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A GLOBAL WARMING INVENTORY FOR THE PROVINCE OF ONTARIO

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EXECUTIVE SUMMARY

A Global Warming Inventory was compiled for the Province of Ontario. Sources, sinks and net emissions of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and chlorofluorocarbons (CFCs) were estimated for the base year 1988, and forecast methodologies were used to predict future inventories up to the year 2010.

The MOE gridded CO_2 and N_2O inventory (ORTECH, 1991) and the Ministry of Energy database (Salamon, 1991) were used as the starting point for this study. Although several base quantities were taken from the MOE files, the 1987 point source quantities were corrected to reflect 1988 values. The SENES inventory was calculated by sector (e.g. all landfills in the province as one source), as opposed to point and area sources by grid locations. Therefore average emission factors were used for each source, as opposed to individual factors for each source location.

An extensive literature search was performed to identify emission factors and forecast methodologies. The inventory methodologies developed for the Intergovernmental Panel on Climate Change (IPCC) by the OECD (Organization for Economic Co-operation and Development) and Environment Canada (Jaques, 1991) were used.

The MOE inventory was verified with information identified from the literature and refined where sufficient information was available. Some new sources were added, particularly natural sources. Uptake by sinks were calculated and subtracted from total emissions to produce net emissions for each greenhouse gas.

The Ministry of Energy base quantities in Petajoules (PJ) were used for all fuel based sources, including transportation, and emission factors (in t/PJ) were adapted from Environment Canada (1990). In other words, the existing Ministry of Energy CO_2 inventory was updated by adding non-energy sources, such as CO_2 from industrial processes (e.g. lime calcination), landfills (using the U.S. EPA Scholl Canyon Model), incineration, fires and wood decay.

Despite the differences in the approach used to create the CO_2 and N_2O inventories, several source types in other jurisdictions have comparable emissions, and similar percentage contributions. However, the net emissions were, as expected, different because of the subtraction of sinks, which have not been estimated in previous inventories.

The CH_4 and CFC inventories were created for Ontario using the methodologies described. No comparisons were made since there are no existing inventories for these gases in Ontario. However, these inventories are expected to be useful as a preliminary estimate of Ontario's contribution to net emissions of CH_4 and CFCs.

Summary of Results for 1988

(In Kilotonnes)	CO_2	N_2O	CH_4	CFCs
Total Sources	224,372	260.9	1,677	11.2
Total Sinks	182,180	16.8	1,181	0.7
Net Emissions	42,192	244.1	496.5	10.5

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1.0 INTRODUCTION

This report describes all components of the study to compile a global warming inventory for the Province of Ontario. The overall objective was to improve the Ministry of Energy and the Ministry of the Environment's inventory and forecast of emissions of Ontario greenhouse gases. All sources (natural and anthropogenic, energy and non-energy related) of the major greenhouse gases are included to the extent that estimates could be made. The aim was to develop a complete inventory of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs), to estimate absorption by sinks, and to calculate net emissions of these gases.

This study will provide the detailed baseline inventory of Ontario's emissions and sinks for each greenhouse gas, in order to provide a basis for emission reduction strategies that deal with the complete spectrum of greenhouse gases.

1.1 BACKGROUND

The global warming phenomenon is the result of increased quantities of certain gases in the atmosphere that act as a transparent shield to short wave radiation (sunshine) allowing it to pass through, while preventing long wave infrared radiation (reflected) from escaping.

In order to evaluate the extent to which greenhouse gas emissions will influence future atmospheric composition and climate, it is necessary to identify all significant sources of these gases and sinks for them. The following table from Houghton et al. (1990) outlines the major characteristics of the greenhouse gases studied during this project.

Characteristics of Greenhouse Gases

GAS	MAJOR CONTRIBUTOR TO GLOBAL WARMING?	LONG LIFETIME IN THE ATMOSPHERE?	SOURCES KNOWN?
Carbon dioxide	yes	yes	yes
Methane	yes	no	semi-quantitatively
Nitrous oxide	not at present	yes	qualitatively
CFCs	yes	yes	yes
HCFCs, etc.	not at present	mainly no	yes
Ozone	possibly	no	qualitatively

1.2 SCOPE OF WORK

The main project tasks were as follows:

- to complete and quality assure an inventory of Ontario greenhouse gas emissions (CO_2, N_2O, CH_4 and CFCs) including uptake by sinks;
- to suggest methodologies for forecasting net greenhouse gas emissions;
- to suggest a reference forecast of net greenhouse gas emissions and where possible uptake by sinks.

The inventory is based on the year 1988. Emissions are provided for other years (i.e. 1989 and 1990) where data was available. The base quantities for the inventory were adapted from the Ministry of Environment database (1988 area source files, and 1987 point source files, which were converted to equivalent 1988 base quantities). Forecast parameters have been applied to 1988 base quantities to estimate future emissions, sinks and net emissions of greenhouse gases up to and including the year 2010.

2.0 EMISSIONS INVENTORY METHODOLOGY

The reliability and accuracy of the emission factors are reflected by a rating system (A through E, with A being the most reliable and accurate). This rating system reflects the quality and amount of data on which the factors are based, and is similar to the system applied to the U.S. EPA AP-42 emission factors (U.S. EPA, 1985). In general, factors based on many observations are assigned higher rankings. Conversely, a factor based on a single observation of questionable quality, or one extrapolated from another factor for a similar process, would be labelled D or E. These ratings are subjective and take no account of the inherent scatter among the data used to calculate emission factors. Therefore, they should be used only as approximations, to indicate the level of confidence in particular emission factors.

Emission factors were adapted from Environment Canada (Jaques, 1990, 1991) and/or OECD (1991) when available. However, in situations where emission factors were not available, compiled values from the literature were chosen, using the ranking scheme outlined above.

2.1 CARBON DIOXIDE (CO_2)

Estimates of carbon dioxide emissions include carbon monoxide (CO). CO in the atmosphere undergoes complete oxidation to CO_2 within 5 to 20 weeks after emission. CO_2 emission estimates have been altered in order to account for the portion of carbon that initially forms CO and CH_4, to eliminate any double counting (Jaques, 1991).

Through a joint Energy, Mines and Resources and Environment Canada Sources & Sinks Working Group, a consensus was reached on the emission factors to be used for carbon dioxide. A common set of emission factors is essential to produce a consistent set of emissions.

2.1.1 Anthropogenic Sources - Energy Related Emissions

Most emissions of CO_2 are directly related to fuel combustion and not particular processes, therefore emissions depend almost entirely on the carbon content of the fuel burned. It is more important that all fuels and their uses be accurately accounted for, than whether or not an allocation to a particular company can be made.

The amount of CO_2 emitted is directly related to: (1) the amount of fuel consumed, (2) the fraction of the fuel that is oxidized, and (3) the carbon content of the fuel. Emissions are proportional to the fuel heating value (a higher heating value (HHV) requires less fuel consumption for a given amount of energy production). Jaques (and SENES) used the HHV, while the OECD (1991) recommends using the LHV, which would be more appropriate because the emissions are in the vapour phase, which reflects the actual release situations.

2.1.1.1 Stationary Fuel Combustion

Most CO_2 fuel-based emission factors in this inventory are based on Environment Canada estimates as shown in Table 2.1.1 (Jaques, 1990).

Gas Utilities and Natural Gas Producers

CO_2 emissions from gas utilities arise mainly from the combustion of fuel gas to run compressors, and from power heaters and other processing equipment. Natural gas contains a significant amount of CO_2 which is stripped out in order to meet product specifications. Natural gas is also flared after completion of wells, and during drill stem and gas well testing.

Electricity Generation

Emission factors for each of the fuels used to generate electricity have been developed by Environment Canada (Jaques, 1990). Since CO is assumed to convert to CO_2 within 0.4 years (Jaques, 1989 as cited by B.H. Levelton & Associates, 1990), there is very little difference between actual and estimated CO_2 levels.

Table 2.1.1

ENVIRONMENT CANADA CO_2 EMISSION FACTORS FOR FUEL

Fuel Type	Carbon Dioxide
Gaseous Fuels	(tonnes/Petajoule (t/PJ)
Natural gas	49,680
Liquid Fuels	
Motor gasoline	67,980
Kerosene	67,650
Aviation gasoline	69,370
Propane	59,840
Diesel Oil	70,690
Light Oil	73,110
Heavy Oil	74,000
Aviation Turbo	70,840
Solid Fuels	
U.S. Bituminous	88,900
Cdn. Bituminous	92,100
Sub-bituminous	99,000
Lignite	108,400
Petroleum Coke	94,420
Fuel Wood	81,470

Source: Jaques, 1990

Residential Fuel Combustion

This sector consists of area sources (single and multiple dwellings) burning residual oil, distillate oil or natural gas.

Commercial Fuel Combustion

This sector consists of area sources burning distillate oil, residual oil, natural gas, kerosene and bottled gas. Point sources include the following fuel categories: coal, distillate oil, residual oil, natural gas, process gas, propane, solid waste and liquid waste.

Industrial Fuel Combustion

This sector consists of point (external combustion boilers and in-process fuel) and area sources in the MOE inventory. The inventory includes coal, distillate oil, residual oil and natural gas (for both point and area sources), and in addition, kerosene for point sources, and process gas, wood/bark waste, solid waste, coke, propane and butane for area sources.

Wood Burning

This area source consists of residential fuel wood combustion.

2.1.1.2 Non-Stationary Fuel Combustion

Transportation sources are divided into the following sectors, as provided by the Ministry of Energy: motor gasoline, diesel, aviation turbo, aviation gas and heavy fuel oil.

ORTECH (1991) reported CO_2 emission rates from motor vehicles are a function of the fuel economy (km/litre) and fuel characteristics (grams of carbon per litre of fuel). Mobile 4O (Ontario-Specific Version of Mobile 4) was used to derive a CO_2 emission factor for each vehicle class specific to the Ontario 1988 vehicle fleet (Black, 1988 as cited by ORTECH, 1991).

However, there is a discrepancy in the current version of the model, and revisions are in progress (Wong, personal communication, 1991).

CO_2 emission factors from transportation (tonnes per Petajoule or t/PJ) sources were derived from the Ministry of Energy database, which are based on the calculations of Jaques.

The CO_2 emission factor for all motor vehicles consuming gasoline is 18.54 t/TJ. Based on fuel usage figures, emissions are divided into on-road and off-road uses of gasoline. Based on DuPont's Escon computer model (DuPont, 1983 as cited by Jaques, 1990) fleet average fuel efficiencies derived for automobiles, light-duty trucks, heavy-duty trucks and motorcycles were estimated to be 8.5, 4.71, 2.62 and 14.18 km/L respectively. The gasoline usage splits obtained were 65.10% autos, 27.51% light-duty trucks, 7.14% heavy-duty trucks and 0.29% motorcycles.

CO_2 emissions from diesel-powered vehicles were based on an emission factor of 19.28 t/TJ and vehicle splits of 10.02% light-duty diesel vehicles (LDDV) and 89.98% heavy-duty diesel vehicles (HDDV). The OECD (1991) reports uncontrolled emission factors for LDDV and HDDV, however, Jaques emission factor was used.

2.1.2 Anthropogenic Sources - Non Energy Related Emissions

2.1.2.1 Cement Manufacturing

Cement production represents the major non-energy source of industrial CO_2 emissions. CO_2 is produced during the production of lime, calcium oxide (CaO). In cement kilns, calcium carbonate ($CaCO_3$) from calcium-rich materials such as limestone and chalk are heated to form lime and CO_2 in a process called calcination. The lime combines with silica-containing materials such as clays or shales, to form dicalcium or tricalcium silicates, two of the major compounds in powdered cement. (OECD, 1991)

An emission factor of 0.5 t CO_2/t cement is reported by Jaques (1990) and Marland et al. (1989), based on an average 63.5% calcium oxide content in cement.

2.1.2.2 Lime Manufacturing

Lime production involves calcining limestone at high temperature to drive off carbon dioxide from the carbonate rock. Both high calcium and dolomitic limestone may be processed from the quarried limestone. Emissions related to fossil fuel combustion for these facilities are included with the industrial fuel combustion sector (ORTECH, 1991). An average emission factor of 0.85 t CO_2/t quicklime produced was applied based on individual facility emission factors ranging between 0.79 and 0.92 t CO_2/t quicklime produced.

2.1.2.3 Kraft Pulp and Paper Manufacturing

Wood is digested with caustic (NaOH) to produce pulp at about a 45% yield. The remaining 55% leaves the process with inorganic chemicals as black liquor. The black liquor is burnt in chemical recovery boilers to produce process steam, resulting in CO_2 emissions.

$CaCO_3$ is converted to CaO in a lime kiln. CO_2 emissions from lime kilns are estimated using a ratio of CaO generated per tonne of pulp produced, the molecular weight ratio of CO_2 and CaO, and the amount of Kraft pulp produced annually (B.H. Levelton & Associates, 1990).

ORTECH (1991) reported that approximately 0.79 t CO_2 is emitted per tonne of lime produced. This converts to 0.20 t CO_2 per tonne of pulp produced, and was applied to all point source facilities in the MOE database.

2.1.2.4 Coke Production

Metallurgical coke is produced in slotted coke ovens at integrated iron and steel plants, and used primarily in blast furnaces and other high temperature operations at these facilities. During the production and use of coke, the amount of CO_2 vented directly from coke ovens during pyrolysis of coal is highly uncertain, since a portion will be contained in the coke off-gas used in other heating processes. Similarly, the amount of CO_2 generated by coke consumption in the blast furnaces in conjunction with recirculation of the blast furnace gas is uncertain. The emissions from these operations are assumed to occur within the same year of the initial coke production (ORTECH, 1991). The amount of coal consumed at each facility is contained in the MOE inventory point source files with designation to either oven charging or coke quenching.

Jaques (1990) derived an emission factor of 2.39 t CO_2/t coal, assuming an average fraction of 6% of coal that results in coke by-products such as light oils and crude tars. This emission factor applies to coal used in coke ovens at the four primary steel producers in Ontario, and to the beehive coke ovens used at other facilities (ORTECH, 1991). However, it was not applied in the industrial section of the inventory since this would double-count the iron and steel coal based CO_2 emissions under the fuel section.

2.1.2.5 Solid Waste Disposal

Municipal Waste Incineration

CO_2 emissions from the combustion of urban waste depends almost entirely on the carbon content and therefore the energy content of the waste. An emission factor of 0.246 t carbon (or 0.902 t CO_2) per tonne of waste incinerated was used by Jaques (1990).

Sewage Sludge Incineration

Sewage sludge is incinerated mainly in four multiple-hearth incinerators in Ontario. Source test data from three facilities were used to derive an average factor of 0.66 t CO_2/t dry sludge incinerated (range 0.44 to 0.95), as reported by ORTECH (1991).

Industrial/Commercial Incineration

Industrial and commercial incinerators are usually of an intermediate size, capable of burning 25 to 1,800 kg refuse per hour. CO_2 emissions are estimated to be similar to those from municipal incinerators (Jaques, 1990). Emission factors for various point sources in the MOE inventory range from 0.55 to 2.47 t CO_2/t waste. In order to calculate a representative (average) emission factor for incineration in Ontario, a weighted average of all point sources was derived (0.86 t CO_2/t waste incinerated).

Wood Waste Incineration

Wigwam burners are used for the disposal of sawdust in the lumber and plywood industries. CO_2 emissions are calculated using the derived emission factor for wood combustion, which is 0.4 tonnes carbon (or 1.47 t CO_2) per tonne of wood waste incinerated (Jaques, 1990).

Landfills

The U.S. EPA Scholl Canyon Model was used to estimate emissions of CO_2 and CH_4 from landfills in Ontario. This model is described in Section 2.3.2.1. Gas collection systems are in operation at the Keele Valley and Brock West landfills. The collected gas is then flared, and all the collected methane is assumed to be effectively converted to CO_2. Therefore, this amount of CO_2 is then added to the CO_2 emitted from the landfills. Table 2.1.2 lists the total predicted CO_2 emissions from landfills in Ontario.

2.1.2.6 Forest Harvesting

The release of carbon dioxide from forest harvesting arises from decay of biomass on-site (roots, stumps, slash, twigs), oxidation of wood products removed from the site (paper, lumber, waste) and oxidation of soil carbon. The uptake by regrowth of trees and redevelopment of soil organic matter following harvest should be subtracted from potential emissions (Houghton et al., 1990). The area harvested in Ontario was 237,000 hectares for 1988 and the area regenerated was 181,000 hectares (Forestry Canada, 1990).

The OECD (1991) suggests a methodology for calculating carbon emissions from the conversion of forests to permanent cropland and pasture. The relevant portion of this methodology was used to calculate CO_2 emissions from forest harvesting. The cleared carbon (55% of the above ground carbon) decays over an average of about ten years.

Table 2.1.2

CO_2 EMISSIONS FROM LANDFILLS IN ONTARIO

Year	CO_2 Emissions	CO_2 Equivalent of CH_4 Collected (tonnes)	Total CO_2
1988	1,677,600	114,389	1,791,989
1989	1,743,000	146,526	1,889,526
1990	1,808,800	159,844	1,968,644
1991	1,843,200	173,162	2,016,362
1992	1,873,400	186,480	2,059,880
1993	1,901,200	199,799	2,100,999
1994	1,926,800	213,117	2,139,917
1995	1,950,000	226,435	2,176,435
1996	1,970,800	239,762	2,210,562
1997	1,988,600	239,762	2,228,362
1998	2,004,000	239,762	2,243,762
1999	2,016,000	239,762	2,255,762
2000	2,026,000	239,762	2,265,762
2001	2,034,000	238,563	2,272,563
2002	2,044,000	237,376	2,281,376
2003	2,054,000	236,201	2,290,201
2004	2,064,000	235,038	2,299,038
2005	2,076,000	233,886	2,309,886
2006	2,086,000	231,547	2,317,547
2007	2,098,000	229,232	2,327,232
2008	2,108,000	226,939	2,334,939
2009	2,120,000	224,670	2,344,670
2010	2,134,000	222,423	2,356,423

$$\text{Carbon emission} = (\text{annual forest area cleared}) \times (\text{above ground carbon per unit forest area}) \times 0.55 \times 0.10$$

Therefore, the amount of CO_2 released by forest harvesting in 1988 is:

$$237{,}000\ ha \times 73.0\ \frac{tonne\ C^{*}}{ha} \times 0.55 \times 0.10 \times \frac{44\ tonne\ CO_2}{12\ tonne\ C}$$

$$= 3.49 \times 10^6\ tonnes\ CO_2$$

* average carbon content in primary and secondary temperate deciduous and boreal forests (OECD, 1991).

2.1.2.7 Slash Burning

Slash is burned for three main reasons: to reduce the hazard of forest fires, to promote the growth of seedlings and to control insects. Information on the quantity of slash burned is based on primary forest production and emissions are estimated from the CO_2 emission factor for wood (Jaques, 1990). The amount of slash burned in Ontario in 1988 was 90,309 t (MOE area source file), and the emission factor of 1.47 t CO_2/t wood burned was applied (Jaques, 1990).

2.1.2.8 Raw CO_2

Raw CO_2 is released directly to the atmosphere during natural gas production, and is based on estimates of the CO_2 concentration in gas fuels performed by the Energy Resources Conservation Board (ERCB). The ERCB estimates were based on available information of CO_2 content in gas plant inlet volumes, CO_2 released from unprocessed gas used in field production, and CO_2 emitted from gas well testing, solution gas flaring and gas plant shutdown flaring. As the overall average CO_2 content is not expected to change significantly in the future, the annual emission rate is proportional to natural gas production (Alberta Energy Efficiency Branch, 1990).

The Alberta Energy Efficiency Branch (1990) assumed fuel gas use in the gas processing industry to be 7% of total marketable gas, divided into: field use (2%), gathering system (1%) and processing plant (4%). Raw CO_2 emissions were calculated as 4% of fuel gas use in processing plants. Therefore, raw CO_2 emissions in 1988 were $0.04 \times (0.04 \times 3.66 \times 10^5)$ tonnes = 585.6 tonnes CO_2.

2.1.2.9 Natural Gas Transportation

The emission of CO_2 from this source was based on the ORTECH (1991) value of 233.4 t/km multiplied by 8778 km of pipeline, which is 2.05×10^6 tonnes CO_2. This amount was then based on the amount of marketable production (2.05×10^6 tonnes CO_2/366480 tonnes natural gas = 5.59 tonnes CO_2/tonne natural gas), for the purpose of forecasting.

2.1.2.10 Wood Products Decay

Wood products that decay naturally emit CO_2. This emission was estimated based on Jaques (1991) national CO_2 inventory, by multiplying the national emission level with the fraction of population (Ontario versus Canada). Jaques obtained this estimate from the ESSA Limited/Forestry Canada forest carbon cycle database, but results of the database were not available to SENES, nor is this database broken down by province.

2.1.2.11 Other

Other miscellaneous sources of CO_2 emissions include dry ice, liquid CO_2, compressed CO_2, fire extinguishers, carbonated drinks, CO_2 to control pH in waste water treatment plants and CO_2 stripped from natural gas. There were no estimates available from the literature for these areas for inclusion in this report.

2.1.3 Natural Sources

2.1.3.1 Water Bodies

No information was found in the literature for emissions from this source.

2.1.3.2 Land

More than 80% of carbon added in crop residues is converted to CO_2 within several years of application. Tillage mixes and aerates the soil, which stimulates microbial activity and degradation of soil organic matter. Reduced or zero tillage reduces CO_2 emissions and sequesters more carbon in the soil.

There were no emission factors identified for application to soils in Ontario. Personal communication with several researchers at the University of Guelph (Department of Land Resource Science) revealed that there are several ongoing research projects, but results and conclusions are not yet available.

2.1.3.3 Soil Organic Matter

A fraction of organic carbon in roots and plant residues will be fixed in soil in the form of humic substances for long periods of time, while more degradable substances will be oxidized rapidly as a result of biological activity. Previously fixed carbon will therefore be returned to the atmosphere (through biological decomposition and respiration). Eventually an equilibrium is established, where carbon gains and losses are balanced. In certain situations, carbon fixation is greater than mineralization, such as in peatlands (see Section 3.1.4).

2.1.3.4 Forest Fires

Ontario has an average of 1,790 forest fires per year, based on the ten year average from 1980 to 1989. The average annual area burned during that period was approximately 232,450 hectares per year. In 1988, 3,260 fires were recorded, burning about 390,706 hectares. Jaques (1990) converts the area burned into the amount of wood burned to determine the CO_2 emissions from forest fires. The MOE area source value of 8,582,834 t of wood burned in 1988 and an emission factor of 1.47 t CO_2/t wood (Jaques, 1990) was used in the present inventory.

2.2 NITROUS OXIDE (N_2O)

2.2.1 Anthropogenic Sources - Energy Related Emissions

N_2O emissions from stationary sources result from fossil fuel combustion activities for the commercial, institutional and industrial sectors and electric power generation (where coal is by far the principal fossil fuel used). Residential wood combustion also results in relatively small quantities of N_2O emissions. Research has indicated that N_2O formation may be linked to the nitrogen content of fuels. It is now believed, however, that emission values have been overestimated prior to June 1988 due to a sampling artifact occurring in stored grab samples containing nitric oxide (NO) and sulphur dioxide (SO_2). Evidence now implies that direct N_2O emissions from conventional fossil fuel combustion are low, although N_2O formation may occur indirectly following combustion in the exhaust plume or in the atmosphere through mechanisms involving NO_x. Recent research suggests that emerging technologies such as fluidized bed combustion and non-selective catalytic reduction methods for NO_X control using ammonia, urea and cyanuric acid may promote N_2O emissions. The overall importance of combustion activities to N_2O production is still unclear. (OECD, 1991)

Most of the fuel related emission factors in the inventory were taken from the MOE inventory (ORTECH, 1991) and converted from t/t and t/m^3 to t/PJ, using the related fuel properties.

Since no specific information was available, ORTECH (1991) applied the N_2O emission factor for wood combustion to all municipal incinerators (0.16 kg N_2O/t wood burned, as cited by Jaques, 1991). Similarly, the same factor was applied to all sewage sludge and industrial/commercial/institutional incinerators, as well as to wigwam burners. (Wigwam or conical burners are used for the disposal of sawdust and other wood wastes in the lumber and plywood industries).

2.2.2 Anthropogenic Sources - Non Energy Related Emissions

2.2.2.1 Non-Stationary Fuel Combustion

Production of N_2O emissions from non-stationary sources results from automotive, railroad, some marine and aircraft sources, with by far the largest contribution being from automotive sources. N_2O formation in internal combustion engines is not yet well understood but involves two processes which occur during the actual combustion process in the cylinder and in the catalytic after-treatment of exhaust gases. N_2O emissions are formed primarily during cold-starts of catalyst-equipped vehicles. Quantification of N_2O emissions from automotive sources is difficult because of the number of vehicle categories and the various types of catalysts which may be installed. Concentrations of N_2O from automotive sources may have been underestimated in the past because the effects of aging catalytic equipped vehicles was not taken into account. When compared with stationary combustion sources, mobile sources are considered to be the most significant in N_2O emissions, even though total N_2O emissions from both stationary and mobile sources make up a small share of overall total greenhouse gas emissions (OECD, 1991).

Fuel combustion base quantities from transportation sources were obtained from the Ministry of Energy, and fuel emission factors from ORTECH (1991) were converted to t/PJ to be used in the present inventory.

2.2.2.2 Industrial Processes

Nitric Acid Production

Nitric acid is an intermediate product formed in the manufacture of nitrogen fertilizers. N_2O emissions may result in its production through ammonia oxidation. The quantity formed depends on factors such as gas composition, reaction conditions, reactor design and catalyst type as well as the type of plant and emission controls present.

ORTECH (1991) reports a median emission factor of 8.5 kg N_2O/tonne of ammonia consumed for nitric acid (HNO_3) production, based on European test data (range 2.5 to 20 kg/t for individual manufacturing facilities). This median value is converted to 3.44 kg N_2O/t HNO_3 produced (assuming one mass unit of NH_3 produces 2.36 mass units of HNO_3), since the MOE base quantity files also report the amount of HNO_3 produced.

Adipic Acid Production

N_2O is a by-product in the production of monomers 6,6- and 6,12-nylon where adipic acid is a component of the process. Emissions are usually difficult to quantify as the effects of most emission controls on N_2O release is not known. Some process emissions are treated with a reductive furnace which destroys N_2O.

Thiemens and Trogler (1991) approximate an emission factor of 300 kg N_2O per tonne of adipic acid produced.

2.2.2.3 Fertilizer Use

Production of N_2O from the use of nitrate and ammonium fertilizers is difficult to quantify because N_2O fluxes are dependent on fertilizer and soil type, soil temperature, weather and farming practices. Conversion of fertilizer N to N_2O ranges from 0.01 to 2.0%. Leaching of nitrogen fertilizers from soils into ground water may result in additional fluxes of N_2O (OECD, 1991).

The first methodology for calculating N_2O emissions from nitrogen fertilizers is based on the amount of each type of fertilizer nitrogen consumed, and an emission coefficient for the fraction of applied nitrogen that is released as N_2O-N.

The second method is similar to the first, however N_2O-N emissions are summed over all fertilizer and crop types, since crop types have been shown to affect emissions.

The first method is preferred because it is relatively simple, and incorporates the major factor known to influence N_2O emissions, which is fertilizer type (OECD, 1991). Table 2.2.2.1 lists N_2O emissions by fertilizer type, and the following calculation uses these values to estimate the overall emission factor for fertilizer use in Ontario.

ORTECH (1991) reports the annual total fertilizer use in Ontario for the year 1987/1988 obtained from the Fertilizer Institute of Ontario.

Fertilizer Type	Tonne N in Fertilizer	Tonne N_2O-N Emitted	Tonne N_2O Emitted
Anhydrous ammonia	25807	421 (1.63%)	661
Urea	81454	90 (0.11%)	141
Ammonium nitrate	21899	57 (0.26%)	89
Solutions	34093	89 (0.26%)	139
Ammonium sulphate	523	1 (0.12%)	2
Monoammonium phosphate	9894	26 (0.26%)	40
Diammonium phosphate	17972	47 (0.26%)	73
10-34-0	28	0 (0%)	0
Total	191670	731	1,145

Therefore, the overall emission factor is (1,145 ÷ 191,670) calculated as 0.006 t N_2O per t fertilizer (N).

2.2.2.4 Slash Burning

Biomass burning is now thought to be a minor source of atmospheric N_2O (Muzio et al., 1989). This value is one to two orders of magnitude less than previous estimates (Crutzen et al., 1979, 1985 as cited by Houghton et al., 1990) which were influenced by artifacts involving N_2O analysis and N_2O production in sampling flasks.

2.2.2.5 Miscellaneous Sources

Contamination of surface and ground water from leaching and runoff of nutrients from agricultural systems and from sewage systems may be a more significant source of N_2O than direct emission of N_2O from soil surfaces. According to Breitenbeck, 1988 (as cited in OECD,

Table 2.2.2.1

FERTILIZER DERIVED N_2O EMISSIONS BY FERTILIZER TYPE[a]

Fertilizer Type	% N_2O-N produced (Median)	% N_2O-N produced (Range)
ANHYDROUS AMMONIA AQUA AMMONIA	1.63	0.86-6.84
AMMONIUM NITRATE Ammonium Sulphate Nitrate Calcium Ammonium Nitrate	0.26[b]	0.04-1.71
AMMONIUM TYPE Ammonium Sulphate Ammonium Phosphate	0.12	0.02-1.5[c]
UREA	0.11	0.07-1.5[d]
NITRATE Calcium Nitrate Potassium Nitrate Sodium Nitrate	0.03	0.001-0.5
OTHER NITROGEN FERTILIZERS	0.11	0.001-6.84[e]
OTHER COMPLEX FERTILIZERS	0.11	0.001-6.84[e]

[a] Unless otherwise noted all numbers are from Eichner, 1990.

[b] In Eichner's data the median is represented by two data points, 0.12 and 0.40. For this table the average of these data points was taken for a median of 0.26.

[c] The upper limit of the range is from Mosier et al. (1986). The median for the category is based on Eichner's range (0.02-0.90) and therefore does not include the Mosier et al. (1986) estimate.

[d] The upper limit of this range is from Mosier and Bronson (1990). The median for the category is based on Eichner's range (0.07-0.18) and therefore does not include the Mosier and Bronson (1990) estimate.

[e] The constituents of these categories as listed in the 1986 FAO Fertilizer Yearbook (1987) vary considerably. Therefore, the range given here represents the widest range of the emission coefficients by fertilizer type (Fung, 1990, personal communication). The median of the range was not given in Eichner (1990), but was calculated from her data.

Source: OECD, 1991.

1991) approximately 5-30% of applied fertilizer nitrogen leaches or runs off. There is a large uncertainty in emissions from nutrient leaching and runoff, use of organic fertilizers and cultivation of leguminous (nitrogen fixing) crops. No information was found in the literature, for application to Ontario.

Anaesthetic Usage

Based on the tonnes used in the U.S. in 1989 and the associated population, ORTECH (1991) estimated a usage rate of 57.8 g per capita. Based on a 1988 Ontario population of 9.43 million, the total nitrous oxide emission from this source is estimated as 545 tonnes N_2O. ORTECH (1991) assumed that all nitrous oxide used for anaesthetic purposes is released to the atmosphere with negligible metabolism or other removal processes.

Propellant Usage

ORTECH (1991) assumed a usage rate of 3.03 g per capita of nitrous oxide used as a propellant for pressure and aerosol products, based on 1989 U.S. usage and population statistics. The corresponding 1988 Ontario emission from this source is approximately 28.6 tonnes N_2O.

2.2.3 Natural Sources

2.2.3.1 Oceans

The oceans are a significant but not a dominant source of N_2O (McElroy and Wofsy, 1986 as cited by Houghton, et al., 1990). An accurate determination of the global annual ocean flux is difficult because of the uncertainties associated with quantifying the gas exchange coefficient and because the partial pressure of N_2O in the surface waters is highly variable, both spatially and temporally. It is unclear whether N_2O is primarily produced from nitrification in near surface waters, or denitrification in oxygen deficient deep waters.

This topic is only qualitatively addressed here since oceanic sources of N_2O are not applicable in the Province of Ontario.

2.2.3.2 Natural Soils

Nitrous oxide (N_2O) is produced naturally in soils by denitrification (the reduction of nitrite or nitrate to gaseous nitrogen as N_2 or as an oxide of N) and nitrification (the oxidation of ammonia to nitrate). Denitrification in aerobic soils is thought to be a dominant source of atmospheric N_2O. Nitrification under anaerobic conditions could produce higher yields of N_2O per unit of transformed nitrogen. Quantification of global N_2O emissions from soils is difficult because of the heterogeneity of terrestrial ecosystems and the variability in environmental conditions that control the fluxes of N_2O (Houghton et al., 1990).

The following nitrous oxide flux rates from Canadian soils are adapted from Environment Canada (1981), and were used by Jaques (1991) with the assumption that these fluxes should be interpreted as order of magnitude estimates only.

Soil Type	Area (ha)	Emission Factor (kg/ha/y)	N_2O Emission (tonnes)
Chernozemic	N/A*	1.688	-
Solonetzic	N/A*	0.706	-
Luvisolic	12064400	0.427	5151
Podzolic	46318100	3.542	164059
Brunisolic	2684200	0.739	1984
Regosolic	N/A*	0.105	-
Gleysolic	7266300	0.413	3001
Organic	25757600	2.481	63905
Rockland	1473900	0.079	116
Total	95,564,500		238216

* Not applicable in Ontario

Therefore, the average emission rate over all soil types in Ontario (238,216 t N_2O/95,564,500 ha) is 0.0025 t N_2O/ha.

2.2.3.3 Lightning

Production of N_2O emissions due to lightning is considered very small in comparison with quantities from other natural sources, such as soils and marine waters. N_2O emission rates due to lightning over various forest types range from approximately 0.08 to 1.0 mg/m^2/year (Environment Canada, 1981).

The following nitrous oxide flux rates from lightning over forests are adapted from Environment Canada (1981) and were used by Jaques (1991) with the assumption that these fluxes should be interpreted as order of magnitude estimates only.

Forest Type	Area (ha)	Emission Factor (kg N_2O/ha/y)	Emissions (tonnes)
Boreal	42335	0.0061	0.26
Boreal Barrens	24556	0.00305	0.075
Great Lakes - St. Lawrence	19492	0.00845	0.165
Deciduous	2092	0.000845	0.018
Total	88475		0.518

Therefore, the average emission over all forest types due to lightning is (0.518 t N_2O/88,475 ha) or 5.9×10^{-6} t N_2O/ha. This factor was applied to the forested area of Ontario to estimate the emissions of N_2O.

2.2.3.4 Volcanoes

No estimates of N_2O emissions from volcanoes were found in the literature but this source is not a potential cause of concern because there are no volcanoes in Ontario.

2.2.3.5 Forest Fires

N_2O flux rates from forest fires are reported by forest type, by Environment Canada (1981) and used by Jaques (1991). However, forest fire statistics for Ontario were not available by forest type, therefore the wood combustion emission factor of 0.00016 t N_2O/t wood burned (0.16 kg/t) was used for the total amount of forest burned in 1988.

2.3 METHANE (CH_4)

2.3.1 Anthropogenic Sources - Energy Related Emissions

2.3.1.1 Natural Gas

Gas Production

Possible sources of leakage in the natural gas production process include threaded and flanged connections in piping and valves, valve-stem packing, open-ended valves and relief valves, compressor and pump packing, seals and liquid storage tanks vented to the atmosphere (Barns, et al., 1990).

Transmission and Distribution

Transmission refers to the transportation of gas in bulk over long distances. Distribution is the delivery to end-use customers within a localized area. The most likely sources of loss from transmission lines would be at compressor shaft seals, valve-stem packing, relief valves, and flanged joints (not widely used). Distribution systems are extensive networks with a variety of fittings and joints (mostly underground), where slow leaks may remain undiscovered for extended periods of time. Another source of loss is the venting of residual gas in lines and mains to the atmosphere prior to maintenance and the escape of gas from relief valves during system upsets.

The emissions associated with natural gas transmission losses include fugitive emissions, maintenance emissions, equipment exhaust, upsets and mishaps. The ability to estimate these emissions is hampered by the general lack of data on emission factors. The most difficult emissions to estimate are fugitive emissions. Specially designed measurement studies would considerably improve the basis for estimating these emissions (OECD, 1991).

Jaques (1991) reports methane emission estimates that are based on an analysis of distribution losses from member companies of the Canadian Gas Association.

Gross Production[1]	7.2 x 10^8 m^3 (5.2 x 10^5 t)	
Marketable Production[2]	5.1 x 10^8 m^3 (3.66 x 10^5 t)	
Density of Methane	0.72 kg/m^3	
Production Leakage[3]	0.25% of Gross Production	
Transmission Leakage	0.03% of Marketable Production	110 t
Distribution Leakage	0.05% of 50% of Marketable Production	92 t
Total		202 t

[1] Amount of gross production determined by ratio of gross to marketable production reported in Jaques (1991).
[2] Private Communication, Consumers Gas, 1991.
[3] Production Leakage is accounted for separately.

Therefore, the average emission factor is (202 t CH_4/3.66 x 10^5 t) or 0.0006 t CH_4/t marketable production of natural gas. This factor was used to estimate CH_4 emissions from natural gas transportation in Ontario.

2.3.1.2 Stationary Fuel Combustion

Jaques (1991) derived CH_4 emission estimates, from Environment Canada's "Canadian Emissions Inventory of Common Air Contaminants 1985", based on the difference between total hydrocarbon emissions and volatile organic compound emissions. Most of the factors used to estimate these emissions were developed by the U.S. EPA (AP-42, as cited by Jaques, 1991).

The following emission factors were taken from the literature and assigned a rating factor as follows:

Rating	Number of Literature References	Number of Orders of Magnitude Between Highest and Lowest Factors
A	≥10	1
B	≥5 <10	1
C	<5	1
C	≥10	2
D	≥5 <10	2
E	<5	2

Fuel Type	No. of Values	Range of Values	Average (t/PJ)	Rating
LFO - Residential	4	2.0-5.8	4.4	C
LFO - Industrial (Construction)	3	0.3-1.0	0.6	E
HFO - Industrial (Agriculture)	5	1.0-3.0	2.2	B
Natural Gas - Industrial	4	1.1-1.4	1.2	C
Coal - Industrial	4	1.0-2.4	1.6	C
Wood - Residential	3	26-74	49	C

Several emission factors were adapted from OECD (1991) and the U.S. EPA (AP-42, 1985). Since no information on CH_4 emissions from the combustion of certain fuels was found, these factors were derived by assuming that the ratio of CO_2 emission factors for these fuels apply to CH_4. For example,

$$\frac{E.F.\ CH_4\ (Kerosene)}{E.F.\ CH_4\ (HFO)} = \frac{E.F.\ CO_2\ (Kerosene)}{E.F.\ CO_2\ (HFO)}$$

Therefore, the CH_4 *emission factor for kerosene is* $\left(\frac{67,650}{74,000} \times 1.5\right)$ *or* 1.4 *t/PJ*

2.3.2 Anthropogenic Sources - Non Energy Related Emissions

2.3.2.1 Landfills

To estimate methane emissions from landfills in Ontario, detailed information is needed about active and abandoned landfills. For active landfills, the information needed is generally not available. The project time and budget constraints did not allow for the data to be collected from individual municipalities. Also, in many active landfills, a weigh scale is not used and data on the quantities of wastes disposed of are not recorded. For most of the abandoned landfills, there is no data at the municipal level and, in some instances, the municipality has little knowledge of abandoned landfills within its jurisdiction.

To obtain a reasonable estimate of methane emissions, B.H. Levelton & Associates, 1991 used the following general approach:

1. The population (P) of the Province for the period from 1941 to 1990 was obtained from Statistics Canada.

2. Municipal solid waste (MSW) disposed of per capita during the last 50 years was obtained from the published literature.

3. Using the population and MSW disposal per capita, the total municipal solid waste disposed of in every province and territory in a specific year was estimated as follows:

$$TMSW_i = (P)\ (M)\ \frac{(365)}{1{,}000}$$

where

P = population in year i

$TMSW_i$ = total MSW disposed of in the province during year i (t/yr)

M = MSW disposed of per capita (kg/capita/day)

4. The amount of MSW incinerated during year i ($MSWI_i$, t/yr) in the province since 1940 was determined by contacting the municipalities.

5. The MSW landfilled ($MSWLF_i$) is the difference between the total municipal solid waste disposed of ($TMSW_i$) and the amount of MSW incinerated during year i ($MSWI_i$):

$$MSWLF_i = TMSW_i - MSWI_i,\ (t)$$

6. In each province, major municipal landfills were contacted and information about these landfills was obtained, when available. The information included:

- date opened
- date closed
- MSW disposed of every year
- landfill design capacity
- population served by the landfill
- amount of methane gas collected if the landfill is equipped by a gas collection system.

7. The climate parameters from each landfill site including mean daily temperature and yearly precipitation were used to estimate a value of k (kinetic rate constant) for the Scholl Canyon model.

Municipal Solid Waste Deposition

In order to estimate the emissions of methane from landfills it is necessary to estimate the amount of MSW disposed of in the landfills during the past 50 years (see Table B.1 in Appendix B). The estimate was based on MSW generation per capita and the population in each individual province. Table B.2 (Appendix B) shows the amount of MSW disposed of per capita per day.

In some landfills, data about the amount of MSW disposed of each year since it was opened was not available, except for the last few years. In these cases, the annual solid waste disposed of was extrapolated to estimate the amount of MSW disposed of in the landfill since it was opened. The estimate was based on population growth in the province. The approach is illustrated by the following example:

Amount of solid waste disposed of during 1990 was 100,000 t. The amount of MSW disposed of in 1970 (MSW_{70}) is estimated as:

$$MSW_{70} = MSW_{90} \times \frac{P_{70}}{P_{90}} \times \frac{C_{70}}{C_{90}}$$

where

MSW_{70}, MSW_{90} = municipal solid waste disposed of in 1970 and 1990, respectively

P_{70}, P_{90} = population of the province in 1970 and 1990, respectively

C_{70}, C_{90} = the per capita msw disposal rate in kg/capita/day in 1970 and 1990, respectively

The moisture content of the MSW received at the landfill plays an important role in the biodegradation process. Bird and Hale Ltd. et al., (1979) reported that the moisture content from various areas in Canada ranged from 23.8% to 25.3% with an average of 24.4% as-received. This moisture content meets the minimum limit for anaerobic biodegradation process to occur (Mandeville, 1976 as cited by B.H. Levelton & Associates, 1991).

Assumptions for Methane Emission Estimation

To estimate methane emissions from landfills, a number of assumptions regarding waste disposed of and methane generated at landfills in a wide range of different conditions are necessary. This section addresses the assumptions considered in selecting the methane generation model, the efficiency of the gas generation process, values of input parameters of the model, and landfill gas composition.

1. Methane Estimation Model Selection

It is necessary to use the most simplified model available that is consistent with fundamental principles. The model must incorporate different values for the kinetic rate constant to account for variations in landfill conditions and climate. Compared to the other models, the Scholl Canyon model is simple and uses few input parameters, yet it yields results similar to other more complex models if comparable input values are used (McGuinn, 1988 as cited by B.H. Levelton & Associates, 1991).

2. Scholl Canyon Model Input Parameters

The model requires two input parameters, L_o, the potential methane generation capacity of the refuse and k, the kinetic rate constant. The potential methane generation capacity depends on the refuse composition. The higher the cellulose content of the refuse, the higher the value of L_o.

The default value of L_o used in the Scholl Canyon model by the EPA is 8,210 SCF methane/t (U.S. EPA, 1990). It was assumed that the refuse in all municipal landfills has nominally the same composition and has a potential methane generation rate of 8,120 SCF/t. (B.H. Levelton & Associates, 1991)

The methane generation rate constant represents the first order rate from which methane generation decreases after the time of refuse placement. The higher the value of k, the higher the decrease in methane generation rate with time. The value of k is affected mainly by four major factors; refuse moisture content, availability of nutrients for methanogens, pH and temperature. Moisture content and temperature in the landfill are governed by the climatic conditions at the site, including precipitation and ambient temperature. Precipitation affects the moisture content of the refuse. In areas where annual precipitation is relatively high, the moisture content of the refuse on site will be high and, consequently, methane generation rate will be higher (high value of k). Table 2.3.2.1 lists temperature, precipitation and k values for various regions in Ontario (B.H. Levelton & Associates, 1991).

Temperature and microbial activity affect each other within a landfill environment. Ambient temperature may significantly affect the temperature of the landfill, especially for shallow landfills in cold climates. It has been reported that methane generation decreases significantly when the landfill temperature falls below 10°C (Pacey and Degier, 1986 as cited by B.H. Levelton & Associates, 1991).

The combined effect of the above factors determines the methane generation rate in a landfill. The impact of individual factors on the methane generation rate is not fully understood and test data is limited. The information reported in the literature generally reflects the combined effect of these factors. Typically 50% to 60% of the landfill gas volume would be methane.

The data base for L_o and k in the Scholl Canyon model is not large enough to be confident about the values which should be used in the many different climatic zones and landfill areas in Ontario. Additional data for L_o and k at numerous landfills having a wide range of characteristics is needed before the accuracy of the landfill methane inventory could be improved using this model. Table 2.3.2.2 shows the wide range of L_o values determined from previous studies.

The Scholl Canyon Model was therefore used to estimate emissions of CH_4 (and CO_2) from landfills in Ontario. Since data on the individual landfills was not available, the total amount landfilled in Ontario was input as one landfill. The quantities from 1941 to 1990 were obtained from B.H Levelton & Associates (1991) (see Table B.1) and the estimates for 1991 to 2010 are

Table 2.3.2.1

TEMPERATURE, PRECIPITATION AND k VALUES USED FOR THE INVENTORY CALCULATIONS

Region	Main Daily Temperature (°C)	Mean Annual Precipitation (mm)	Kinetic Rate* Constant, k yr^{-1}
Barrie	6	700	0.02
Belleville	6	700	0.02
Brantford	6	700	0.02
Brockville	6	700	0.02
Cornwall	6	700	0.02
Guelph	6	700	0.02
Hamilton	6	700	0.02
Kingston	6	700	0.02
Kitchener	6	700	0.02
London	6	700	0.02
North Bay	2.5	650	0.01
Oshawa	6	700	0.02
Ottawa-Hull	6	700	0.02
Peterborough	6	700	0.02
St. Catherines	7.5	800	0.025
Sarnia	6	700	0.02
Sudbury	2.5	600	0.010
Thunder Bay	2	600	0.010
Timmins	1	550	0.006
Toronto	7.5	700	0.025
Windsor	7.5	800	0.025
Other			0.02

* Value of "k" determined through discussions between B.H. Levelton & Associates and the authors of the model.

Table 2.3.2.2

VALUES OF POTENTIAL METHANE GENERATION CAPACITY OF REFUSE FROM THE PUBLISHED LITERATURE

	Estimation Method	Estimated L_0 ft^3 CH_4/Mg Refuse	Assumptions Made
1	Balanced Stoichiometric	8,120 - 9,540	Chemical composition of composite refuse, $C_{99}H_{149}O_{59}N$, and of paper ($C_{203}H_{334}O_{138}N$) and food wastes ($C_{16}H_{27}O_8$)
2	Biodegradability of Materials	220 - 8,120 (1,660 average)	Assumes 1.5 kg biodegradable COD/kg volatile solids and 351 L/kg biodegradable COD
3	Biodegradability of Materials	1,660 average	Wet, composite refuse is 70% decomposable organics: 50% of decomposable organics is volatile; 375 L gas/kg volatile matter, 50% of gas is CH_4
4	Biodegradability of Materials	4,240	Wet composite refuse is 70% decomposable organics: 70% decomposable organics converted to gas; 690 L gas/kg decomposable organics, 25% moisture content; 50% of gas is CH_4
5	Total Organic Content	6,700 - 9,540	1 mol organic carbon yields 1 mol gas; CH_4 is 50% of gas produced, 100% of organic carbon is converted to gas
6	Stoichiometric Equation	7,400	For overall municipal solid waste
7	Stoichiometric Equation	8,100	For overall municipal solid waste
8	Weighted Biodegradability	6,000	---
9	Weighted Biodegradability	3,200	---
10	Weighted Biodegradability	4,200	---
11	Weighted Biodegradability	2,100	---

Note: Entries 1 through 5 are based on Mg of wet refuse, where as entries 6 through 11 are based on Mg of dry refuse. Entries 1 through 5 were not converted to dry refuse basis since % moistures were not known.

Source: McGuinn, 1988

described in Table B.3. (Table B.2 lists the solid waste disposal factors used by B.H. Levelton & Associates).

The landfill gas model was developed to estimate the amount of methane gas that can be collected by a gas recovery system. Therefore to estimate the amount of methane generated by a landfill, the result from the model must be divided by an assumed recovery efficiency expressed as a fraction. B.H. Levelton & Associates (1991) assumed the efficiency of methane collection to be 50%.

Table 2.3.2.3 describes the results from the model, the amount of gas collected, and the resulting methane emissions from landfills in Ontario.

2.3.2.2 Transportation

The U.S. EPA (1990) estimates CH_4 emissions for light and heavy duty diesel and gasoline-fuelled vehicles based on the AP-42 federal test procedure methane offsets. These offsets are emissions of CH_4 emission factors in units of GMT (grams per mile travelled).

CH_4 emissions for transportation sources were based on the fuels used. Therefore, emission factors were derived from the ratio of CO_2 emission factors related to HFO, as described in Section 2.3.1.2 (Stationary Fuel Combustion).

2.3.2.3 Slash Burning

Methane emissions included in biomass burning are from prescribed fires or slash burning. The emission factor was derived from 5 literature values ranging from 0.0006 to 0.0032 t/t, with an average of 0.002 t CH_4/t slash burned. This factor was given a D rating.

Table 2.3.2.3

CH_4 EMISSIONS FROM LANDFILLS IN ONTARIO

Year	Predicted Emissions	Methane Collected			Actual Emissions (tonnes)
		Brock West	Keele Valley	Total Collected	
1988	611,400	37,421	4,175	41,596	569,804
1989	635,200	43,593	9,689	53,282	581,918
1990	659,200	43,593	14,532	58,125	601,075
1991	671,800	43,593	19,375	62,968	608,832
1992	682,800	43,593	24,218	67,811	614,989
1993	693,000	43,593	29,061	72,654	620,346
1994	702,200	43,593	33,904	77,497	624,703
1995	710,800	43,593	38,747	82,340	628,460
1996	718,200	43,593	43,593	87,186	631,014
1997	724,800	43,593	43,593	87,186	637,614
1998	730,400	43,593	43,593	87,186	643,214
1999	735,000	43,593	43,593	87,186	647,814
2000	738,200	43,593	43,593	87,186	651,014
2001	741,600	43,157	43,593	86,750	654,850
2002	745,000	42,725	43,593	86,318	658,682
2003	748,600	42,298	43,593	85,891	662,709
2004	752,400	41,875	43,593	85,468	666,932
2005	756,200	41,457	43,593	85,050	671,150
2006	760,200	41,042	43,157	84,199	676,001
2007	764,400	40,632	42,725	83,357	681,043
2008	768,600	40,225	42,298	82,523	686,077
2009	773,000	39,823	41,875	81,698	691,302
2010	777,600	39,425	41,457	80,881	696,719

2.3.2.4 Forest Fires

Methane emissions from forest fires were assumed to be similar to emissions from slash burning, therefore an emission factor of 0.002 t CH_4/t wood burned was applied.

2.3.2.5 Coal Mining

CH_4 emissions from coal mining are widely described in the literature. However, a description is not included here because coal mining is not a source in Ontario. All of Ontario's coal is imported and there are no mines currently producing coal (Ontario Mining Association, 1991).

2.3.3 Natural Sources

2.3.3.1 Animal Respiration

Among livestock, the ruminant animals (i.e. cattle, buffalo, sheep and goats) are the major emitters of methane. The rumen, a large "fore-stomach", is the unique physiological characteristic of ruminant animals that causes methane to be created within the animal. The conversion of hydrogen or formate and carbon dioxide (produced by other fermentative bacteria) is believed to be the primary mechanism of methane production, by methanogenic bacteria in ruminant animals. Methane produced is emitted through eructation and exhalation.

Since methane is produced as a result of digestive processes, the amount produced varies with animal type, the type, amount and digestibility of feed consumed and the production level.

The recommended methodology for estimating methane emissions from domestic animals is to estimate the amount as a percentage of the amount of feed energy that the individual animal consumes.

Data on CH_4 emissions from animals are very limited. The most precise method is to measure emissions from individual animals that represent categories of animals. Table 2.3.3.1 shows

Table 2.3.3.1

METHANE PRODUCTION OF ANIMALS IN ONTARIO

Animal	Population[1]			CH_4 Production[3] by Individual (kg/yr)
	1988	1989	1990	
Horses	300,000	300,000	300,000	18.00
(Total) Cattle	2,285,000	2,250,000	2,250,000	55.00
Sheep	201,000	212,000	215,000	8.00
Goats	32,460	32,460	32,460	5.00
Turkeys	3,100,000	3,100,000	3,108,852	2.00
Swine	3,370,000	3,230,000	3,151,000	1.50
Humans[2]	9,431,100	9,578,700	9,731,200	0.05
Chickens			32,008,175	3.00
Wild Animals[4]				
Moose	120,000 (aerial estimate)			31.0[5]
Deer	350,000 - 400,000			15.0[5]
Caribou	15,000 - 20,000			31.0

Sources:

[1] All populations (humans not included) obtained from Ontario Ministry of Food and Agriculture (personal communication, 1991).

[2] Human population figures obtained from Statistics Canada (personal communication, 1991).

[3] Jaques, 1991.

[4] Ministry of Natural Resources, Wildlife Branch (personal communication, 1991).

[5] B.H. Svensson et al., 1991.

information found to date on animal population estimates and associated methane generation capacities. Methane emissions are estimated by multiplying individual emission factors (t CH_4/animal) by each animal population (number of animals).

2.3.3.2 Animal Manure

Animal wastes are principally composed of organic material, which produces methane when it decomposes in an anaerobic environment. Methane produced from animal wastes will depend on the waste characteristics and how the waste is managed. The potential emission from each waste type is primarily a function of quantity and quality of the degradable organic material content, or volatile solids (VS) content, of the waste. The VS content is generally a function of animal type and feed.

A very limited amount of data are available to describe uncontrolled methane production and emissions under common waste management practices. The effect of animal type on methane production must be determined in order to quantify methane emissions from waste. Important factors include typical live animal mass, the total manure produced, the total quantity of solids and volatile solids and the types and number of waste management systems in use.

Casada and Safley (1990) have estimated methane emissions from livestock and poultry manure in Canada, on a province wide basis. The characteristics of the manures, including production per unit mass of animal are given in Table 2.3.3.2, and the potential ultimate methane production for each type of animal manure is given in Table 2.3.3.3. The methane producing potential of each type of animal waste management system is given in Table 2.3.3.4.

Temperature extremes could potentially affect most waste management systems by enhancing anaerobic digestion at high temperatures or by inhibiting the process at low temperatures (below 4°C). Canada is classified as a country with very cold winters temperatures, therefore methane emissions of all systems were assumed to be reduced by 20% when averaged over the whole year. This reduction was incorporated with a weather factor (0.8) applied to obtain methane conversion factors for those countries.

Table 2.3.3.2

ANIMAL WASTE CHARACTERISTICS FOR THE UNITED STATES AND CANADA

Animal Type	Typical Live Animal Mass, Kg	Total Manure (kg/d/1,000 kg LAM)[1]	Total Solids (kg/d/1,000 kg LAM)[1]	Volatile Solids (kg/d/1,000 kg LAM)[1]
Beef Cattle	360	58	8.5	7.2
Dairy Cattle	640	86	12	10
Swine	61	84	11	8.5
Layer	1.8	64	16	12
Broiler	0.9	85	22	17
Turkey	6.8	47	12	9.1
Sheep	27	40	11	9.2
Goat	64	41	13	9.5[2]
Horse	450	51	15	10

[1] kg per day per 1,000 kg Live Animal Mass.
[2] estimate.

Source: ASAE (1988) as cited by Casada and Safley, 1990.

Table 2.3.3.3

POTENTIAL METHANE PRODUCTION FROM ANIMAL WASTES - U.S. AND CANADA

Animal Type, Category	B_o, m^3 CH_4/kg VS	Reference
Cattle:		
Beef, on feed	0.33	Hashimoto et al. (1981)
Beef, not on feed	0.17	Hashimoto et al. (1981)
Dairy	0.24	Morris (1976)
Swine:		
Breeder	0.36	Summers & Bousfield (1980)
Market	0.47	Chen (1983)
Poultry:		
Layers	0.34	Hill (1982 & 1984)[1]
Broilers	0.30	Casada & Safley, 1990[2]
Turkeys	0.30	Casada & Safley, 1990[2]
Sheep:		
On feed	0.36	Casada & Safley, 1990[3]
Not on feed	0.19	Casada & Safley, 1990[3]
Goats:	0.17	Casada & Safley, 1990[4]
Horses:	0.33	Ghosh (1984)

[1] Adjusted value.
[2] Based on Hill (1984).
[3] Based on Jain et al. (1981) and Hashimoto et al. (1981).
[4] Based on Hashimoto et al. (1981).

Source: Casada and Safley, 1990.

Table 2.3.3.4

PERCENTAGE OF POTENTIAL METHANE PRODUCTION (MCF) FOR VARIOUS ANIMAL WASTE MANAGEMENT SYSTEMS - U.S. AND CANADA

System	MCF (Percent of B_o)
Daily spread (solid/semi-solid)[1]	5%
Solid storage[2]	10%
Anaerobic lagoon[1]	90%
Liquid/slurry storage[1]	20%
Drylot[2]	10%
Pit storage, less than one month[1]	10%
Pit storage, more than one month[1]	20%
Deep pit stacking[1]	5%
Litter[1]	10%
Pasture/Range[2]	10%
Paddock	10%

[1] Authors' estimate; no data available in the literature.

[2] Based on Chen et al. (1988).

Source: Casada and Safley, 1990.

The annual methane emissions were calculated according to the equation:

$$TM = \frac{VS \times 1{,}000 \times 365 \times MCF \times Bo \times Density}{1{,}000} \quad tonnes/y \qquad (4)$$

where

VS = volatile solids content of waste

MCF = methane conversion factor, potential of emissions averaged over all waste management systems

Bo = methane emission potential for the waste type

and density of methane = 0.662 kg/m^3.

Parameters compiled from Tables 2.3.3.2 to 2.3.3.4 were used to calculate individual emission factors for each type of animal (see Table 2.3.3.5). These emission factors were multiplied by each animal population to estimate methane emissions from animal manure.

2.3.3.3 Oceans and Freshwaters

Oceans and freshwater are believed to be minor sources of atmospheric CH_4. Open oceans are only slightly supersaturated in CH_4 with respect to its partial pressure in the atmosphere. There are inadequate recent data from either the open oceans or coastal waters to reduce the uncertainty in these estimates (Cicerone and Oremland, 1988, as cited by Houghton et al., 1990).

There were no values found in the literature, for application to lakes in Ontario.

2.3.3.4 Wetlands

The largest concentration of wetlands is in the northern hemisphere between 40 and 70°N, covering the ecological regions of the cool temperature, boreal and subarctic forest zones.

Table 2.3.3.5

METHANE FROM ANIMALS IN ONTARIO

Animal	Animals (1988)	Total Mass (Mg)	VS (Mg/d)	MCF	Methane (tonnes)	Emission Factor (t/animal)
Beef Cattle	1,279,600	460,656	3,317	0.084	16,830	
Dairy Cattle	959,700	614,208	6,142	0.103	36,687	
Total Cattle	2,239,300				53,517	0.0239
Swine	3,370,000	205,570	1,747	0.144	25,231	0.0075
Layer	13,120,000	23,616	283	0.155	3,609	
Broiler	18,880,000	16,992	289	0.1	2,094	
Total Chickens	32,000,000				5,703	0.0002
Turkey	3,100,000	21,080	192	0.1	1,391	0.0004
Sheep	201,000	5,427	50	0.1	332	0.0017
Goat*	32,460	2,077	20	0.1	81	0.0025
Horse*	300,000	135,000	1,350	0.1	10,765	0.0359

* MCF values were not provided and were assumed to be 0.1.

The 1990 summer field research program of the Canadian Institute for Research in Atmospheric Chemistry (CIRAC) Northern Wetland Study was designed to measure the flux of methane from the Hudson Bay Lowland (HBL), since the HBL is the second largest continuous wetland in the world, accounting for 12% of the global peatland area. Previous studies had concluded that the northern wetlands were a major source of methane but were based upon very few measurements and a limited knowledge of the extent of global wetlands.

Fluxes in the southern end of the HBL range from 6 to 8 mg/m^2/day in coastal fens to an average of 35 mg/m^2/day in ponds and flooded depressions. The HBL may produce 10 to 40% of the previously estimated amount, possibly due to low organic matter content, the nature of peatland thermal and moisture conditions and the availability of nutrients (CIRAC Newsletter, Summer 1991).

The CIRAC Northern Wetland Study showed that methane emissions may not be as significant as previously estimated. Although the final results of the study have not been released, SENES was able to obtain preliminary estimates for this inventory. These values were used to derive emission factors for each wetland region. The area of each wetland region was estimated by a Geographical Information System (GIS).

The area of coverage by wetland region was computed by combining the Wetland Regions and the Distribution of Wetlands maps (Energy, Mines and Resources Canada, 1986a, b). Polygons were digitized and classified according to the respective maps. A third map was created by combining the information from the first two maps by computing the corresponding area from coincident polygons. Figures B.1, B.2 and B.3 illustrate the approach used within the GIS system, to characterize the area of wetland regions in Ontario.

Table 2.3.3.6 shows the area of each wetland region (the areas derived from the GIS approach were normalized according to the total wetland area in Ontario, National Wetland Working Group (NWWG), 1986).

Table 2.3.3.6

CALCULATION OF METHANE EMISSIONS FOR THE PROVINCE OF ONTARIO

Wetland Region	Area (ha)	Flux Rate ($g/m^2/y$)	Emission (tonnes/y)
[1] Temperate	3.90×10^5	1.477	5,755
[2] Low Boreal	2.71×10^6	1.633	44,274
[3] Mid Boreal	1.10×10^7	1.633	179,203
[4] High Boreal	6.10×10^6	1.785	108,885
[5] Sub-Arctic	9.03×10^6	2.467	222,770
Total	2.92×10^7		560,887

Therefore the average emission over all wetland regions in Ontario is (560,887 t divided by 2.92×10^7 ha) 0.019 t/ha.

Sources of Information:

[1] Calculated spatially weighted flux (see Appendix B).

[2] Roulet, et al., 1991.

[3] Roulet, personal communication, 1991.

[4] Roulet, 1992.

[5] Roulet, 1992. The area weighted emission factor for the low and high subarctic regions is 2.467 $g/m^2/y$, based on measurements in the Hudson Bay Lowlands. 83% of the HBL is in Ontario.

2.3.3.5 Termites

There is a large range in the magnitude of estimated CH_4 fluxes from termites; 10-100 Tg/year. The values are based on laboratory experiments and applied to estimates of global termite populations and the amount of biomass consumed by termites (both of which are uncertain), and field experiments (Houghton et al., 1990).

The termite population in Ontario was not available to SENES, therefore no emission was calculated.

2.3.3.6 Tundra

Methane emissions from tundra contributes about 10% of the global atmospheric methane budget. However, future lowering of the water table as a result of a warmer, drier climate will decrease CH_4 fluxes, due to the increased CH_4 uptake by microbial oxidation (Whalen and Reeburgh, 1990). Whalen and Reeburgh (1988, as cited by Fung et al., 1991) report low levels of methane fluxes (approximately 0.005 $g/m^2/day$) emanating from dry tundra. However, there were no tundra areas identified in Ontario, therefore no emission was calculated.

2.4 CHLOROFLUOROCARBONS (CFCS)

The Commercial Chemicals Branch of Environment Canada has acquired data on the usage of CFC and CFC substitutes. This information is necessary to provide a complete picture of CFCs, HFCs ad HCFCs. However, SENES was told that this information is confidential and as such was not released to us for the purpose of this study.

In February 1989, Ontario became the first province to ban products that destroy the ozone layer. About half of all CFCs and halons produced in Canada are used in Ontario. Table 2.4.1 contains the summary of CFC usage in Canada. Section 2.4.2 describes the method used to estimate CFC emissions in Ontario.

Table 2.4.1

SUMMARY OF CFC USAGE IN CANADA (1987)

Process Group	CFC's Used	Total Estimated Usage (Kilotonnes)	CFC Usage Overall (Percent)
Refrigeration and Air Conditioning	-11, -12, -113, -114, -115*	7.5	36.1%
Rigid Foams	-11, -12, -113, -114	6.9	33.2%
Flexible Foams	-11	1.7	8.2%
Aerosol Products	-11, -12, -113, -114	1.9	9.1%
Solvents	-113	2.0	9.6%
Other Applications (Includes Sterilants)	-12, -113	0.8	3.8%
Total		20.8	100.0%

Source: Commercial Analysis of Chlorofluorocarbon Applications in Canada, Project Report prepared for Chemical Department, Environment Canada, 1988.

Note:

CFC-11	CCl_3F
CFC-12	CCl_2F_2
CFC-13	$CClF_3$
CFC-113	$C_2Cl_3F_3$
CFC-114	$C_2Cl_2F_4$
CFC-115	C_2ClF_5

* There are no CFC-115's produced in Canada.

2.4.1 Anthropogenic Sources - Energy Related Emissions

None of the literature sources identified to date have listed CFC emissions from energy related activities.

2.4.2 Anthropogenic Sources - Non Energy Related Emissions

The only emission factors found for CFCs were those based on the methodology derived by Gamlet et al. (1986) and adapted by Jaques (1991). The time delay for releases from the varied uses of CFCs must be estimated in order to calculate the overall release rate of CFCs. The most efficient method is to group the uses of each CFC into the six categories below:

- aerosols
- hermetically sealed refrigeration (long lifetime, about 12 y)
- non-hermetically sealed refrigeration (short lifetime, about 4 y)
- closed cell foams
- open cell foams
- other uses

The subdivision of foam into open cell and closed cell types is not easily verified because of the differences in reporting of company sales data.

Fugitive Emissions

Emissions of CFCs occur during production. These emissions are estimated at 0.02 tonnes of emissions per tonne of CFC-11 produced, 0.033 tonnes of emissions per tonne of CFC-12 produced and 0.025 tonnes of emissions per tonne of other CFCs produced. Since all Canadian production occurs in Ontario, these factors were applied to Canadian production to get emissions from Ontario. All other emissions relate to Ontario use of CFCs.

Emission Factor (E.F.) = $0.02\ P_t$ (for CFC 11)
= $0.033\ P_t$ (for CFC 12)
where P_t = annual production in year t

Aerosols, Solvents, Miscellaneous

CFCs used as aerosols, solvents, in other miscellaneous ways, and closed cell foams are assumed to be released about six months after they are produced. Thus the emissions in any given year are equal to half of the consumption from the previous year and half of the consumption in the current year.

E.F. = $0.5\ S(A)_t + 0.5\ S(A)_{t-1}$
where S(A) = annual sales
t-1 = year of sale
t = the following year

Long-Lived Refrigeration

It was assumed that of the total CFC-12 sold for refrigeration, 8% was of the long-lived variety.

CFC-12 is used in refrigerators and is assumed to be released at the end of the 12 year life of the appliance. Annual emissions are calculated as 0.08 times the total amount of CFC-12 in use in refrigerators in that year. The amount of CFC-12 in Ontario refrigerators at the beginning of 1988 is estimated at 22,500 tonnes. This amount is updated annually by subtracting the quantity emitted and adding the quantity consumed for refrigeration purposes. SENES considers this to be an over-estimate as more CFCs are captured for reuse each year.

E.F. = $(0.08 \times TR) * x/100$
where TR = total production of CFCs for refrigeration
x = percentage of CFC 12 sold in 1988 for long-lived uses
(x = 58% for Canada in 1987)

Short-Lived Refrigeration

CFC-11 (short-lived refrigeration) and other CFCs used for refrigeration are assumed to be released during the year in which they are produced. Automobile and some household air conditioners fall into this category, where on average, the refrigerant is recharged every four years. Therefore, the emissions in this category are also an overestimate of the actual release.

Open Cell Foam

When used in the production of open cell foams, CFCs are estimated to be released about two months after they are produced. Thus the emissions from open cell foams during a given year are estimated as 0.17 times consumption during the previous year plus 0.83 times consumption during the current year.

E.F. = $0.83\ S(OC)_t + 0.17\ S(OC)_{t-1}$
where S(OC) = sales of open cell foams

Closed Cell Foam

Closed cell foam can be subdivided into:

- rigid polyurethane and isocyanurate foams (CFC-11)
- non-urethane foams, polystyrene and some extruded polyolefins (mainly CFC-12 when the blowing agent is CFC)

CFC-12 is mostly used for polyolefin foam. Assuming most of the CFC is lost to the atmosphere within 2 years and 75% is lost within 1 year,

E.F. = $0.5\ S(CC)_t + 0.5\ S(CC)_{(t-1)}$
where S(CC) = sales of closed cell foams

CFC 11 is mostly used in rigid polyurethane where the three principal factors that determine release are production loss, diffusion loss during product use and losses on disposal.

Other

Other uses include CFC-12 in sterilizing gas mixtures and CFC-11 and CFC-12 as solvents. These are treated similarly to aerosols with a 6 month release delay.

Base Year Production of CFCs in Canada

A survey of CFC users by Environment Canada found total use of CFCs in Canada to be 20,300 tonnes in 1988 (see Table 2.4.2). This survey distinguishes the applications in which the CFCs were used, but not the types of CFCs. In this survey, Canadian production of CFCs in 1988 is assumed to be equal to Canadian use of CFCs in that year, namely 20,300 tonnes.

A report by The DPA Group (1989) relates Canadian production of CFCs by type to global production. Canadian production of CFC-11 was 1.44% of global production in 1985. Canadian production of CFC-12 was 1.98% of global production in 1985. A survey by Grant Thornton (Chemical Manufacturers Association, 1990) reports global production of CFC-11 and CFC-12 in 1988 at 375,986 and 421,002 tonnes respectively. Assuming that the 1985 percentages still applied in 1988, the Canadian production of CFC-11 and CFC-12 was calculated to be 5,410 and 8,340 tonnes respectively. This allows the calculation of Canadian production of other CFCs as (20,300 - 5,410 - 8,340) or 6,550 tonnes in 1988.

Canada has only two plants that produce CFCs. They are both located in Ontario so all production is assumed to occur in Ontario.

Base Year Use of CFCs in Ontario

Ontario consumption of CFCs is assumed to be 50% of the Canadian total by type and application (DPA Group, 1989). Thus the Environment Canada survey data (see Table 2.4.2) can

Table 2.4.2

CFCS USES IN CANADA

	1986		1987		1988		1989	
	Tonnes	Percent	Tonnes	Percent	Tonnes	Percent	Tonnes	Percent
Refrigeration & Air Conditioning	6,500	33	6,800	33	7,000	34	7,700	44
Foam	8,200	42	9,200	44	8,900	44	6,700	39
Solvent	1,800	9	1,900	9	2,200	11	2,100	12
Aerosol	2,250	12	2,180	11	---	---	---	---
Miscellaneous	700[1]	4	700[2]	3	2,200[3]	11	900[4]	5
Total	19,450	100	20,780	100	20,300	100	17,400	100

Note:

1) Sterilization (85%), Testing Gas (6%), Others (9%).
2) Sterilization (76%), Testing Gas (6%), Others (18%).
3) Aerosol (73%), Sterilization (22%), Leak Testing (4%), Others (1%).

Source: Environment Canada Survey of CFC Users, provided by Commercial Chemicals Branch, 1991.

be used to estimate the quantity of CFCs used in each application in Ontario (Table 2.4.3). Information from the Grant Thornton survey was used to estimate the proportions of CFC-11 and CFC-12 in various applications. However, these proportions do not reconcile to the total use by application and the total use of each type of CFC. Hence, the quantity of each type of CFC in each application was adjusted to ensure reconciliation to the estimated total for each type of CFC and for each application. The results are not overly sensitive to these adjustments since most CFCs are estimated to be released relatively quickly.

CFC Substitutes

A number of hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) are being considered as potential replacements for the long-lived CFCs (11, 12, 113, 114, 115) that are regulated under the terms of the Montreal Protocol:

HCFC-22	$CHClF_2$
HCFC-123	$CHCl_2CF_3$
HCFC-124	$CHClFCF_3$
HFC-125	CHF_2CF_3
HFC-134a	CH_2FCF_3
HCFC-141b	CH_3CCl_2F
HCFC-142b	CH_3CClF_2
HFC-143a	CH_3CF_3
HFC-152a	CH_3CHF_2

These compounds also act as greenhouse gases. The hydrogen atoms in these compounds makes them more reactive, so they have a shorter life in the atmosphere and are less likely to reach the stratosphere where the chlorine and fluorine react with the ozone. The shorter atmospheric life makes them less of a threat to the stratospheric ozone layer. Nevertheless, they remain a threat to the ozone layer and the amended Montreal Protocol calls for HCFCs and HFCs to be phased out during the first two decades of the next century.

Table 2.4.3

CFC USE IN ONTARIO 1988

	CFC11	CFC12	OTHER	TOTAL
REFRIGERATOR	400	1,800	1,300	3,500
OPEN CELL	165	1,070	-	1,235
CLOSED CELL	2,140	500	575	3,215
SOLVENT	-	-	1,100	1,100
AEROSOL	-	800	-	800
MISCELLANEOUS	-	-	300	300
TOTAL	2,705	4,170	3,275	10,150

It has been estimated (UNEP, 1989 as cited by Houghton et al., 1990) that a mix of HFCs and HCFCs will replace the CFCs currently in use at a rate of about 0.4 kg of substitute for every kg of CFCs currently produced, with an annual growth rate of about 3%.

2.5 EMISSIONS FROM FUELS IMPORTED TO ONTARIO

This section provides global warming gas emission coefficients for fuels imported to Ontario. The coefficients cover the entire fuel cycle prior to combustion, including extraction, refining/processing, and transportation. The coefficients cover two sources of emissions along the fuel cycle: combustion emissions (emissions from fossil fuel combustion at each step of the fuel cycle) and fugitive emissions (leaks and releases at each step of the fuel cycle). Table 2.5.1 presents the fuel cycle emission coefficients.

2.5.1 Overview of Approach

The fuel cycle emission coefficients were calculated as the sum of combustion coefficients and fugitive coefficients. This section provides an overview of the approaches used to develop each set of coefficients. The following sections provide more detail on the sources and calculations used to develop combustion coefficients.

Combustion Coefficients

Combustion emission coefficients were developed by first estimating the energy intensity (joule consumed per joule delivered) required at each step of the fuel cycle for each fuel imported to Ontario. Intensities were developed for each fuel utilized in the fuel cycle, including coal, coke, heavy fuel oil, light fuel oil, natural gas and electricity. These intensities were then multiplied by end use emission coefficients to estimate combustion coefficients for each fuel consumed at each step of the fuel cycle. Combustion coefficients for the entire fuel cycle were derived by summing across fuels and fuel cycle steps.

This approach is similar to that used by the California Energy Commission (CEC) in developing

Table 2.5.1
Fuel Cycle Emission Coefficients
(tonne emission per PJ of fuel delivered to Ontario)

	Carbon Dioxide	Methane	Nitrous Oxide
Combustion emissions			
Western Canada coal	1,319	0.004	0.034
Pennsylvania coal	1,162	0.016	0.030
Western Canada crude oil	4,611	0.040	0.097
Western Canada natural gas	7,796	0.169	0.085
Uranium	11,287	0.092	0.257
US electricity	252,069	1.460	6.007
Fugitive emissions			
Western Canada coal		41.140	
Pennsylvania coal		522.191	
Western Canada crude oil			
Western Canada natural gas		58.939	
Uranium			
US electricity			
Total emissions			
Western Canada coal	1,319	41.145	0.034
Pennsylvania coal	1,162	522.207	0.030
Western Canada crude oil	4,611	0.040	0.097
Western Canada natural gas	7,796	59.108	0.085
Uranium	11,287	0.092	0.257
US electricity	252,069	1.460	6.007

its 1988 Inventory of California Carbon Dioxide Emissions (CEC, 1990). However the CEC approach was adapted to reflect Ontario data and circumstances wherever possible.

Fugitive Coefficients

Fugitive emission coefficients were calculated based on data developed by Environment Canada (Environment Canada, 1991), by converting Environment Canada's coefficients into units common to the combustion coefficients (tonnes emission per PetaJoule of fuel delivered).

Environment Canada estimates fugitive coefficients only for methane releases from coal mining and natural gas pipelines. Additional carbon dioxide releases may occur during coal, oil, and natural gas mining. However, sufficient data was not available to estimate carbon dioxide fugitive emission coefficients.

2.5.2 Combustion Coefficients: Energy Intensity Estimates

Table 2.5.2 presents the energy intensity estimates for each fuel delivered to Ontario, for each step of the fuel cycle, and for each fuel consumed in the fuel cycle. With the exception of uranium extraction and electricity production, intensities were developed by first estimating the annual energy consumption (for each fuel consumed) and then dividing by the annual energy production. For example, Western Canada coal intensities were developed by first estimating the amount of natural gas and electricity consumed by Alberta's coal industry during 1988 and then dividing by the amount of coal produced in Alberta during 1988. Note that electricity production is defined as deliveries rather than generation to account for transmission and distribution losses.

Table 2.5.3 presents data sources and basis (geographical region and year) used to develop intensities for fuel extraction and electricity production, respectively. In addition, the tables provide comments on any additional assumptions or adjustments that were necessary to develop the intensity estimates.

Uranium extraction intensities were based directly on the CEC estimates, which are developed

Table 2.5.2
Fuel Cycle Energy Intensity
(Joule consumed per Joule delivered)

	FUEL CONSUMED IN FUEL CYCLE							
	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
Western Canada Coal								
Extraction	0.0000	0.0000	0.0000	0.0000	0.0005	0.0010	0.0000	0.0015
Transportation				0.0138				0.0138
Total	0.0000	0.0000	0.0000	0.0138	0.0005	0.0010	0.0000	0.0153
Pennsylvania Coal								
Extraction	0.0005	0.0000	0.0040	0.0004	0.0000	0.0000	0.0027	0.0076
Transportation				0.0026				0.0026
Total	0.0005	0.0000	0.0040	0.0030	0.0000	0.0000	0.0027	0.0102
Western Canada Crude Oil								
Extraction	0.0000	0.0000	0.0000	0.0060	0.0145	0.0041	0.0000	0.0245
Flaring					0.0009			0.0009
Transportation						0.0078		0.0078
Total	0.0000	0.0000	0.0000	0.0060	0.0153	0.0118	0.0000	0.0332
Western Canada Natural Gas								
Extraction/processing	0.0000	0.0000	0.0000	0.0000	0.0882	0.0056	0.0000	0.0938
Flaring					0.0061			0.0061
Transportation					0.0303			0.0303
Total	0.0000	0.0000	0.0000	0.0000	0.1246	0.0056	0.0000	0.1302
US Uranium								
Extraction/refining	0.0000	0.0000	0.0000	0.0008	0.0170	0.0000	0.0463	0.0640
Total	0.0000	0.0000	0.0000	0.0008	0.0170	0.0000	0.0463	0.0640
Electricity								
Michigan total	2.4927	0.0000	0.0586	0.0100	0.0074			2.5687
Alberta total	2.8331	0.0000	0.0000	0.0000	0.1538			2.9870
Pennsylvania total	2.1308	0.0137	0.1426	0.0232	0.0083			2.3185

Table 2.5.3

FUEL EXTRACTION ENERGY INTENSITY DATA SOURCES, BASIS AND COMMENTS

Western Canada Coal

Basis: 1988, Alberta
Consumption source: Alberta Energy, 1990
Production source: National Energy Board, 1990.

Comments: Only national consumption data was available. Alberta was assumed to provide 80% of national coal production.

Pennsylvania Coal

Basis: 1982, United States
Consumption source: California Energy Commission, 1990.
Production source: California Energy Commission, 1990.

Western Canada Crude Oil

Basis: 1988, Alberta
Consumption source: Alberta Energy, 1990
Production source: National Energy Board, 1990.

Western Canada Natural Gas

Basis: 1987, Alberta
Consumption source: Alberta Energy, 1990.
Production source: National Energy Board, 1990.

Comments: Alberta Energy only provides consumption data beginning in 1988. 1987 values were estimated by adjusting 1988 values for one year of growth. 1987-88 growth was assumed to be the same as 1988-89 growth.

Table 2.5.3 Continued

FUEL EXTRACTION ENERGY INTENSITY DATA SOURCES, BASIS AND COMMENTS

US Electricity	
Basis:	1989, Michigan
Consumption source:	US Energy Information Administration, 1990.
Deliveries source:	US Energy Information Administration, 1990.
Alberta Electricity[1]	
Basis:	1988, Alberta
Consumption source:	Alberta Energy, 1990.
Deliveries source:	Alberta Energy, 1990.
Pennsylvania Electricity	
Basis:	1989, Pennsylvania
Consumption source:	US Energy Information Administration, 1990.
Deliveries source:	US Energy Information Administration, 1990.

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[1] Alberta fuel intensities were developed for application to end use electricity consumed by Western Canadian fuel industries. Similarly, Pennsylvania intensities were applied to electricity consumption by Pennsylvania's coal industry.

from an engineering analysis of the uranium fuel cycle. Note that the CEC could not develop a uranium transportation coefficient due to a lack of adequate data. Note also that the CEC reports its estimates as primary fuel intensity rather than end use intensity. That is, it converts end use electricity consumption to primary fuel consumption by adjusting for power plant heat rate. For consistency, all intensities are reported in units of end use energy consumed per unit of fuel produced (or delivered).

Energy intensities were developed for flaring and transportation based on the intensity estimates developed by the CEC. Note that the CEC developed its flaring, natural gas pipeline and coal transportation estimates based on annual consumption and production estimates for the U.S. national oil, natural gas and coal industries. CEC's transportation intensities were adjusted to reflect the distances that fuels travel to Ontario.

The CEC developed its oil pipeline intensities based on engineering analyses of typical pipelines. Adjustments were made to the CEC's estimate for distance travelled by Ontario crude deliveries, as well as the efficiencies of pipeline prime movers. (The CEC assumes reciprocating engines for prime movers while we assume electric motors on Canadian oil pipelines).

2.5.3 Combustion Coefficients: End Use Emission Coefficients

For fuels not used to generate electricity, carbon dioxide and nitrous oxide end use emission coefficients were based directly on Environment Canada (Environment Canada, 1990 and 1991) estimates and methane coefficients directly on U.S. Environmental Protection Agency (U.S. EPA 1990) estimates. All coefficients were converted to units of mass per unit of energy consumed for use in the energy intensity estimates. End use coefficients represent combustion emissions only and exclude additional fuel cycle emissions.

For fuels used to generate electricity, end use coefficients were developed using the same approach described above for fuel cycle combustion emissions by import fuel. That is, energy intensities were first estimated for each fossil fuel used in electricity generation. These energy intensities were multiplied by end use emission coefficients for each fossil fuel and then summed across fuels to arrive at end use emission coefficients for electricity generation. Separate electricity generation end use coefficients were developed for Alberta and Pennsylvania. Alberta coefficients were applied to all western Canadian fuel production and transport. Pennsylvania coefficients were applied to Pennsylvania coal production and U.S. uranium production.

Emissions of Greenhouse Gases from Fuels Imported to Ontario

A Lotus 1-2-3 spreadsheet called IMPORTS has been created to calculate the emissions of greenhouse gases outside Ontario associated with the production and transportation of fuels imported into the province. The quantity of each of the major fuels (Western Canadian Coal, Pennsylvania Coal, Western Canadian Crude Oil, Western Canadian Natural Gas, and U.S. Electricity) imported to Ontario must be specified in petajoules.

The spreadsheet then applies the coefficients listed in Table 2.5.1. This gives the emissions of carbon dioxide, methane and nitrous oxide annually for each of the fuels imported into Ontario. Table 2.5.4 lists the 1988 CO_2, N_2O and CH_4 emissions from fuels imported to Ontario. The total emissions were 24,430 kt CO_2, 0.37 kt N_2O and 318.9 kt CH_4.

TABLE 2.5.4
1988 EMISSIONS FROM FUEL IMPORTS

SOURCE	1988 EMISSIONS (Tonnes)		
	CO_2	N_2O	CH_4
Coal - Canada	140,336	4	4,378
Coal - U.S.	566,178	15	254,442
Crude Oil - Canada/U.S.	10,386,894	181	142
Natural Gas - Canada/U.S.	8,991,962	91	53,016
Electricity - Canada	0	0	0
U.S. electricity	2,260,051	54	13
NGLs - Canada/U.S.	1,165,164	12	6,870
REFINED PETROLEUM PRODUCTS FROM CANADA/U.S.:			
Coke	0	0.0	0.0
LPGs	1,143	0.0	0.0
Motor Gasoline	362,368	6.3	5.0
Kerosene & Stove Oil	22,206	0.4	0.3
Diesel Fuel Oil	210,465	3.7	2.9
Light Fuel Oil	34,406	0.6	0.5
Heavy Fuel Oil	90,520	1.6	1.2
Petroleum Coke	67,996	1.2	0.9
Aviation Gasoline	12,436	0.2	0.2
Aviation Turbo Fuel	118,141	2.1	1.6
Total Refined Petroleum Products	919,681	16.0	12.6
TOTAL FUELS	**24,430,266**	**372.3**	**318,874**

3.0 METHODOLOGY FOR SINKS

3.1 CO_2 SINKS

The rate at which carbon is captured and stored in various ecosystems is estimated from the net primary productivity, which is the amount of organic matter left after natural respiration losses of CO_2 are subtracted from the total amount of CO_2 fixed by photosynthesis (gross primary productivity).

CO_2 sinks are important in helping to balance anthropogenic CO_2 emissions to the atmosphere. Since these sinks are highly variable in terms of photosynthesis, respiration, storage and transport of organic carbon, estimates of CO_2 sinks are subject to considerable error. SENES estimates this error to be approximately 30 to 40%.

3.1.1 Forests

Eriksson (1991) estimates that more than half of the carbon released as carbon dioxide during fossil-fuel combustion is currently accumulating in terrestrial ecosystems, mainly in the form of forest biomass. The carbon balance for forest ecosystems is a function of net primary production, biomass harvest, loss of organic substances in runoff, increase in forest biomass storage, increase in the total organic content of soils and decomposition within the forest.

Changes in soil carbon storage are difficult to estimate. Organic carbon does not accumulate indefinitely in well-drained soils, but rather an equilibrium level between litter supply and decomposition is attained over time, governed by soil-forming factors like climate, topography, vegetation, organisms and parent material.

Long term studies indicate that in response to a change in management practices on cultivated mineral soils, the carbon content reaches a steady-state after a few decades. Because most of the currently used practices have been applied for some decades, an approximate steady-state may have been reached for most arable soils. Assuming a balance between net primary production and decomposition, soil organic-carbon content and the amount stored in biomass should remain constant over time.

The mean annual increment (Bickerstaff et al.) of forest growth per annum is 85.186 x 10^6 m^3. The growth rate of trees is a function of site and stand attributes such as species, structure, age, climate, water and nutrient availability, and silviculture practices. In this report an average value was used in order to make gross estimates of carbon dioxide uptake. Using a conversion factor of 0.45 kg/m^3 (L. Shenfeld, personal communication, 1991) the amount of carbon uptake by Ontario forests is 38 x 10^6 t/yr.

The Carbon Dioxide Inventory Report for British Columbia by Levelton et al. calculated a total carbon uptake of 54 x 10^6 t based on growth of various species in mature and immature forests. Comeau (as cited by B.H. Levelton & Associates, 1990) estimated the annual rate of carbon fixation by forests, by comparing the standing crop of merchantable wood in 1981 and 1986. This accumulation of wood, when converted to carbon content, represented an average annual gross increment of 53 x 10^6 t of carbon. Using the mean annual increment from Bickerstaff et al. for B.C. of 117,335 m^3 the amount of carbon uptake results in 53 x 10^6 t which was the Comeau estimate. The agreement between the two methods adds confidence to the estimate of carbon uptake by Ontario forests.

3.1.2 Agricultural Lands

Agricultural ecosystems are not considered important sinks because except for orchard trees, they are typified by rapid accumulation and removal of biomass, with no opportunity for long-term accumulation of carbon as in a forest (B.H. Levelton & Associates, 1990).

3.1.3 River Transport of Carbon to Coastal Regions

Rivers transport a substantial amount of carbon to oceans and lakes. A small fraction of organic carbon may reside in the river channel and floodplain sediment for a fairly long time. Movement of carbon that has been captured by photosynthesis in the river system is regarded as a potential sink. Methodologies employed by B.H. Levelton & Associates (1990) and Eriksson (1991) were reviewed.

Mulholland and Watts (1982) determined a relationship between Annual Riverflow (AR) and Total Organic Carbon (TOC) for rivers in North America as follows:

$$Log\ (TOC) = 1.0\ Log(AR) + 0.86$$

Mean annual river flow for the Ontario Watershed is 9,530 m^3/sec (MNR, 1984) which is 3.005 x 10^{11} m^3 per annum. Substituting for AR in the above equation,

$$\begin{aligned} \text{TOC} &= 2.2 \times 10^{12} \text{ g C/annum} \\ &= 2.2 \times 10^{6} \text{ t C/year} \end{aligned}$$

For comparison with rivers in British Columbia, the carbon emission was estimated by dividing the amount of carbon loss (69,240 g/s, estimated by L. Shenfeld, 1991) by the river flow (9,530 m^3/s), which gives 7.0 gC/m^3. The carbon emission for British Columbia rivers is 6.5 gC/m^3 (B.H. Levelton & Associates, 1990).

3.1.4 Wetlands

When the decomposition of organic matter is retarded by water, peat begins to accumulate. Peat is an organic material with a carbon content greater than 17%.

To estimate the rate of carbon accumulation, the growth rate of peat (cm/y) is multiplied by an estimate of organic carbon content (50%) and a bulk density (0.11 g/cm^3) (Tarnocai, 1988). Using individual average peat accumulation rates for eastern temperate, boreal and subarctic regions (NWWG, 1988), an area weighted average accumulation rate of 5.58 cm/100 y was calculated.

$$\frac{5.58\ cm}{100\ y} \times \frac{0.11\ g}{cm^3} \times 0.5 = 3.07 \times 10^{-3}\ g/cm^2/y$$

$$= 0.307 \textit{ tonnes of carbon accumulation per hectare per year}$$

Since the total area of peatland in Ontario is 22,555 x 10^3 ha (National Wetlands Working Group, 1988), the amount of carbon stored annually as peat is (0.307 t/ha x 22,555 x 10^3 ha) or 6.9 x 10^6 t C.

3.1.5 Lakes

In a lake ecosystem, the dissolved organic carbon is used for photosynthesis by various aquatic plants and algae. The amount of carbon stored in the bottom sediment can be estimated if the carbon flux to the sediment and lake area are known.

There is an organic carbon accumulation in lakes at rates depending on their size and trophic conditions (Mulholland and Elwood, 1982). Meso-eutrophic Lakes Erie and Ontario have a mean rate accumulation of 18 g C/m^2/yr and oligotrophic Lakes Huron and Superior have a mean rate of accumulation of 6 g C/m^2/yr. Multiplying these rates by the area of the Lake, the accumulation is:

Lake Erie	25.7 x 10^9 m^2 x 18 g C/m^2/yr =	0.46 x 10^6 t C/yr
Lake Ontario	18.96 x 10^9 m^2 x 18 g C/m^2/yr =	0.34 x 10^6 t C/yr
Lake Huron	59.6 x 10^9 m^2 x 6 g C/m^2/yr =	0.36 x 10^6 t C/yr
Lake Superior	82.1 x 10^9 m^2 x 6 g C/m^2/yr =	0.49 x 10^6 t/yr
Total Accumulation =		1.65 x 10^6 t/yr

Taking into account U.S. sources vs. Ontario sources and watershed size in the U.S. vs. Ontario the Ontario C sink in these Lakes is estimated as ⅓* x 1.65 x 10^9 kg or 0.55 x 10^6 t C/yr.

Small lakes in Ontario mainly in Northern Ontario have an area of 85.75 x 10^9 m^2. Using a similar method carbon accumulation in small lakes is calculated as:

$$85.75 \times 10^9 \times 6 \text{ g C/m}^2\text{/yr} = 0.51 \times 10^6 \text{ t C/yr}$$

* Personal estimate of L. Shenfeld (1991)

Therefore, the total sink for Ontario carbon to lakes = (0.55 + 0.51) x 10^6 = 1.06 x 10^6 t C/yr.

3.1.6 Oceans

The net flux into the ocean can be estimated from a knowledge of the atmospheric CO_2 concentration, partial pressure (pCO_2) in surface water (for which the data are still sparse), the global distribution of wind speeds over the ocean as well as the relation between wind speed and gas transfer coefficient (which is known to ± 30% only). The aqueous carbonate chemistry in sea water operates such that if the atmospheric CO_2 concentration increases by 10% for example, the concentration of dissolved inorganic carbon in sea water increases by only about 1% at equilibrium. Therefore, the ocean is not as powerful a sink for anthropogenic CO_2 as originally thought (Houghton, et al., 1990).

SENES assumed that this CO_2 sink was not applicable in Ontario.

3.2 N_2O SINKS

The major sink for N_2O is photochemical decomposition in the stratosphere. N_2O has an atmospheric lifetime of approximately 150 to 175 years. The observed rate of growth represents a 30% imbalance between sources and sinks (Hao et al., 1987 as cited by Houghton et al., 1990). Tropospheric sinks such as surface processes in aquatic and soil systems are considered to be small (Elkins et al., 1978, Blackmer and Bremner, 1976, as cited by Houghton et al., 1990).

The majority of chemically active substances are degraded exponentially in time, with a time constant (c):

$$E = E_o * e^{-t/c}$$

where

E = the amount, and

t = time

The constant c is usually called the turnover time or residence time of the gas.

The migration rate of N_2O from the troposphere to the stratosphere is 10 to 15 years. Therefore the rate constant of N_2O transport from the troposphere is $e^{-1/15}$, if one assumes a 15 year migration rate. Therefore, for every tonne of N_2O emitted, 0.936 or 93.6% remains in the troposphere after one year. Therefore, the amount of N_2O transported from the atmosphere in a year is 6.4%. Although it is difficult to estimate the regional sinks resulting from global atmospheric processes (such as the N_2O sink in the troposphere above Ontario), this method was used to obtain a preliminary estimate, in the absence of more specific information.

3.3 CH_4 SINKS

3.3.1 Reaction with Tropospheric OH

Although some CH_4 is taken up by the soil and the oceans, by far the major sink is oxidation by the OH radical to CO_2 in the lower part of the atmosphere (troposphere), with intervening steps of CH_2O (formaldehyde) and CO formation. The specific paths taken depend heavily on the level of oxides of nitrogen present in the atmosphere (Barns, et al., 1990).

$$CH_4 + OH \rightarrow CH_3 + H_2O$$

The rate coefficient for this process is 2.3 x 10^{-12} exp (-1700/T) cm^3/s where T is temperature in Kelvin (DeMore et al., 1987 as cited by Fung et al., 1991).

Fung et al. (1991) outlines the annually averaged total global chemical loss (450 Tg/y) for methane in the atmosphere. The average loss between latitudes 40° to 60°N is 6.6% of the total, or 29.7 Tg/y. SENES has estimated that the area covered by Ontario within the overall area of this band is approximately 1.9%. Therefore, a crude estimate of the methane sink due to reaction with OH radicals in the troposphere is:

$$0.019 \times 29.7 \times 10^6 \ tonnes/y = 5.64 \times 10^5 \ tonnes \ CH_4/y$$

As mentioned in the calculation of the reduction of N_2O in the troposphere, it is difficult to interpolate the global loss of methane to a regional estimate (Ontario). Therefore, this estimate should be considered as very preliminary.

3.3.2 Micro-Organisms Uptake by Soils

Methane oxidizers (methanotrophs) and methane producing bacteria (methanogens) often exist in the same areas. Methanogens are obligate anaerobes, occupying deeper, wetter soil horizons, while methanotrophs are obligate aerobes, occupying surface, aerobic horizons.

Methane uptake rates range from 2 to 5 mg/m^2/day and are controlled primarily by diffusion rates in soils rather than by the more variable biological factors. The significance of soils as a sink for CH_4 is a combination of the flux into the soil, the frequency or time period during which uptake occurs and the area over which it occurs (Harriss, et al., 1991).

Results from laboratory and *in situ* measurements indicate that the capacity of agricultural soils to consume atmospheric methane is substantially decreased compared to that of unperturbed forest soils. This may be due to increased nitrogen content in agricultural soils from fertilization or increased temperature and moisture fluctuations after the forest canopy has been removed (Keller, 1990).

Mean uptake of methane by soil in temperate zones are reported by Born et al. (1990) in the range of 0.09 to 1.3 g $CH_4/m^2/yr$ for forests and 0.002 to 0.2 g $CH_4/m^2/yr$ for cultivated land. Using the mean values of these ranges, the methane sink in Ontario has been estimated to be:

Forests: 80.7×10^{10} m^2 x 0.695 = 56.08×10^4 t CH_4/y
Cultivated Land: 5.65×10^{10} m^2 x 0.101 = $\underline{0.57 \times 10^4 \text{ t } CH_4/y}$

Total = 56.65×10^4 t CH_4/y

3.4 CFC SINKS

There are no significant tropospheric removal mechanisms for the fully halogenated halocarbons such as CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115. They have long atmospheric lifetimes and are primarily removed by photo-dissociation in the mid-upper stratosphere.

Non-fully halogenated halocarbons containing a hydrogen atom such as methyl chloride (CH_3Cl), methyl chloroform (CH_3CCl_3), $CHClF_2$ (HCFC-22) and a number of other HCFCs and HFCs being considered as substitutes for the current CFCs, are primarily removed in the troposphere by reaction with OH. These species have atmospheric lifetimes ranging from about one to forty years, much shorter on average than the fully halogenated CFCs.

Assuming the migration rate of CFCs from the troposphere to the stratosphere is 15 years, the rate constant for CFC transport from the troposphere is $e^{-1/15}$ or 0.936. Therefore, the amount of CFCs remaining in the troposphere is 93.6% of the amount emitted, and the amount removed is 6.4% in any one year.

4.0 GREENHOUSE GAS INVENTORY (1988)

The emission factors and uptake factors described in Sections 2.0 and 3.0 were multiplied by the 1988 base quantities to estimate emissions, sinks, and net emissions for CO_2, N_2O, CH_4 and CFCs. The following sections describe the results of these calculations. The emission factors, base quantities (for 1988) and base quantity units used are listed in Table 4.1. Please note that the land surfaces on page 4 of this table include all lands (including agricultural and forests), but that wetlands are addressed separately.

4.1 CO_2

Table 4.2 contains a summary of the sources, sinks and net emissions of CO_2, as well as the contribution from each type of source. Table 4.2a divides the summary into anthropogenic and natural sources, sinks and net emissions. Figure 4.1 illustrates the information in Table 4.2. The complete list of sources is provided in Table 6.1. Stationary Fuel Combustion is the main contributor of CO_2 emissions (55% of the total) followed by transportation (20%) and Fires and Wood Decay (18%). These proportions compare well with the present MOE inventory (ORTECH, 1991).

The addition of a preliminary estimate of CO_2 uptake by forests, lakes, rivers, wetlands (peat) and soil results in a total CO_2 sink of 182,180 kt. The major sinks for CO_2 are forests (76%), followed by peatlands (14%) and rivers (4%). The total CO_2 emissions (224,372 kt) compare reasonably well with the MOE emission inventory (218,900 kt). Differences are expected due to the separate approaches in calculation of fuel related emission sources, landfill emissions (using the U.S. EPA landfill model), the addition of certain sources (such as raw CO_2 and wood products decay), and because the MOE database uses 1987 and 1988 base quantities, while the SENES inventory is based entirely on 1988.

The 1988 net emission of CO_2 in Ontario is 42,192 kt.

TABLE 4.1
EMISSION FACTORS AND 1988 BASE QUANTITIES

SOURCES	BASE QUANTITY UNITS	BASE YEAR 1988	EMISSION COEFFICIENTS (t/base quantity)		
			CO2	CH4	N2O
OIL PRODUCTS					
RESIDENTIAL					
Total	Petajoules	61.5			
LFO	Petajoules	57.4	73110	4.4	3.5
HFO	Petajoules	0.2	74000	1.5	3.2
Kerosene	Petajoules	3.9	67650	1.4	3.67
COMMERCIAL					
Total	Petajoules	19.5			
LFO	Petajoules	14.8	73110	0.65	3.5
HFO	Petajoules	3.4	74000	1.5	25
Kerosene	Petajoules	1.3	67650	1.4	3.93
INDUSTRIAL					
Total	Petajoules	94.5			
LFO Construction	Petajoules	1.3	73110	0.6	3.514
LFO Mining	Petajoules	0.4	73110	0.6	3.514
LFO Other	Petajoules	0.3	73110	0.6	3.514
HFO Agriculture	Petajoules	0.1	74000	2.18	3.35
HFO Construction	Petajoules	0.1	74000	2.18	3.35
HFO Chemicals	Petajoules	13.5	74000	2.18	3.35
HFO Iron + Steel	Petajoules	14.6	74000	2.18	3.35
HFO Mining	Petajoules	2.6	74000	2.18	3.35
HFO Cement	Petajoules	0.5	74000	2.18	3.35
HFO Pulp + Paper	Petajoules	4.9	74000	2.18	3.35
HFO Other	Petajoules	7.2	74000	2.18	3.35
Kerosene	Petajoules	0.2	67650	2.06	3.93
Diesel Agriculture	Petajoules	9.6	70690	2.1	10.47
Diesel Construction	Petajoules	9.1	70690	2.1	10.47
Diesel Chemicals	Petajoules	0.1	70690	2.1	10.47
Diesel Iron + Steel	Petajoules	0.7	70690	2.1	10.47
Diesel Mining	Petajoules	3.6	70690	2.1	10.47
Diesel Pulp + Paper	Petajoules	2.0	70690	2.1	10.47
Diesel Other	Petajoules	5.0	70690	2.1	10.47
Gasoline Agriculture	Petajoules	9.2	67980	2	7.12
Gasoline Other	Petajoules	1.8	67980	2	7.12
Pet. Coke Mining	Petajoules	1.4	94420	1	2.835
Pet. Coke Cement	Petajoules	3.7	94420	1	2.835
Pet. Coke Other	Petajoules	1.0	94420	1	2.835
TRANSPORTATION					
Total	Petajoules	643.3			
Motor Gasoline	Petajoules	431.2	67980	2.1	7.12
Diesel	Petajoules	140.6	70690	2.1	10.47
Aviation Turbo	Petajoules	59.8	70840	2.1	6.1
Aviation Gas	Petajoules	1.1	69370	2	6.6
Heavy Fuel Oil	Petajoules	10.6	74000	2.18	3.27
OWN USES AND LOSSES	Petajoules	87.5	68770	2	3.11
ELECTRICITY GENERATION	Petajoules	6.5	73250	2.16	3.32

TABLE 4.1
EMISSION FACTORS AND 1988 BASE QUANTITIES

SOURCES	BASE QUANTITY UNITS	BASE YEAR 1988	EMISSION COEFFICIENTS (t/base quantity)		
			CO2	CH4	N2O
NATURAL GAS					
Total	Petajoules	842.2			
Residential	Petajoules	253.5	49680	1.1	0.5
Commercial	Petajoules	152.3	49680	1.2	2.4
Industrial	Petajoules	338.3	49680	1.2	2.4
Transportation	Petajoules	0.5	49680	1.2	2.4
Non-Energy	Petajoules	30.1	49680	1.2	2.4
Own Uses and Losses	Petajoules	58.9	49680	1.2	2.4
Electricity Generation	Petajoules	8.6	49680	1.2	2.4
NGLs					
Total	Petajoules	69.3			
Residential	Petajoules	3.0	59840	1.4	2.9
Commercial	Petajoules	4.1	59840	1.4	2.9
Industrial	Petajoules	14.6	59840	1.4	2.9
Transportation	Petajoules	12.2	59840	1.4	2.9
Non-Energy	Petajoules	35.4	59840	1.4	2.9
Own Uses and Losses	Petajoules	0.0	59840	1.4	2.9
COAL					
Total	Petajoules	551.0			
CANADIAN BITUMINOUS					
Industrial	Petajoules	35.5	92100	-	-
Electricity Generation	Petajoules	70.8	92100	1	10.69
U.S. BITUMINOUS					
Industrial	Petajoules	168.7	88900	-	-
Electricity Generation	Petajoules	246.2	88900	1	10.69
LIGNITE					
Electricity Generation	Petajoules	29.8	108400	1	19.3
WOOD/WASTE					
Total	Petajoules	92.2			
Residential	Petajoules	19.0	81500	48.7	11.35
Industrial	Petajoules	72.2	107380	15	11.35
Electricity Generation	Petajoules	1.0	81470	13.8	11.35
FOSSIL FUEL PRODUCTION					
Natural Gas Production	Petajoules	15.06	2372	0.027	0.045
Natural Gas Transportation	Tonnes	366,480	5.59	0.00055	0.000065
Oil Production	Petajoules	9.63	6290	48.342	0.073
INDUSTRIAL PROCESSES					
Cement Manufacturing	Tonnes	5,440,000	0.5	-	-
Lime Manufacturing	Tonnes	1,667,788	0.85	-	-
Kraft Pulp and Paper	Tonnes	2,206,458	0.2	-	-
Ammonia Production	Tonnes	1,023,000	1.56	-	0.0085
Nitric Acid Production	Tonnes	260,600	-	-	0.0034
Adipic Acid Production	Tonnes	38,836	-	-	0.3
PRODUCT USAGE					
Raw CO2	Tonnes CO2	586	1	-	-
N2O Anaesthetic	Capita	9,431,100	-	-	0.00006
N2O Propellant	Capita	8,634,865	-	-	0.000003

TABLE 4.1
EMISSION FACTORS AND 1988 BASE QUANTITIES

SOURCES	BASE QUANTITY UNITS	BASE YEAR 1988	EMISSION COEFFICIENTS (t/base quantity)		
			CO2	CH4	N2O
CANADIAN CFC PRODUCTION					
Total	Tonnes	20,300			
CFC-11	Tonnes	5,410	-	-	-
CFC-12	Tonnes	8,340	-	-	-
CFC-113	Tonnes	6,550	-	-	-
INCINERATION					
Municipal Waste	Tonnes	798,839	0.902	0.0065	0.00016
Sewage Sludge	Tonnes	231,599	0.66	0.005	0.00016
Industrial Waste	Tonnes	137,394	0.86	0.005	0.00016
Commercial/Institutional Waste	Tonnes	14,425	0.86	0.005	0.00016
Wigwam Burners	Tonnes	578,414	1.47	0.00015	0.00016
LANDFILLS AND SEWAGE TREATMENT					
Landfills	Tonnes CO2	1,791,989	1	-	-
Landfills	Tonnes CH4	569,804	-	1	-
Sewage Treatment Plants	1000000 m3 CH4	180	-	720	-
FIRES AND WOOD DECAY					
Structural Fires	Tonnes	145,932	1.47	0.002	0.00016
Prescribed Fires	Tonnes	90,309	1.47	0.002	0.00016
Forest Fires	Tonnes	8,582,834	1.47	0.002	0.00016
Wood Product Decay	Tonnes CO2	28,208,420	1	-	-
AGRICULTURE					
LIVESTOCK					
Cattle	Cattle	2,285,000	-	0.055	-
Sheep	Sheep	201,000	-	0.008	-
Swine	Swine	3,370,000	-	0.0015	-
Turkeys	Turkeys	3,100,000	-	0.002	-
Horses	Horses	300,000	-	0.018	-
Goats	Goats	32,460	-	0.008	-
Chickens	Chickens	32,000,000	-	0.003	-
MANURE					
Cattle	Cattle	2,285,000	-	0.0239	-
Sheep	Sheep	201,000	-	0.0017	-
Swine	Swine	3,370,000	-	0.0075	-
Turkeys	Turkeys	3,100,000	-	0.0004	-
Horses	Horses	300,000	-	0.0359	-
Goats	Goats	32,460	-	0.0025	-
Chickens	Chickens	32,000,000	-	0.0002	-
Fertilizer Use	Tonnes Fert.[N]	191,670	-	-	0.006
LAND AND WATER SURFACES					
Soils	Hectare	89,119,000	-	-	0.0025
Wetlands	Hectare	29,241,000	-	0.019	-
Lakes and Reservoirs	Hectare	17,739,000	-	0.0024	-
Lightning (over Forests)	Hectare	80,700,000	-	-	0.0000059
Forest Harvesting	Hectare	237000	14.7	-	-

TABLE 4.1
EMISSION FACTORS AND 1988 BASE QUANTITIES

SOURCES	BASE QUANTITY UNITS	BASE YEAR 1988	EMISSION COEFFICIENTS (t/base quantity)		
			CO2	CH4	N2O
WILDLIFE					
Moose	Moose	120,000	-	0.031	-
Deer	Deer	375,000	-	0.015	-
Caribou	Caribou	17,500	-	0.031	-
SINKS					
Forests	Hectare	40,000,000	3.48	0.014	-
Lakes	Hectare	17,739,000	0.219	-	-
Rivers	1000000 m3	300,500	26.9	-	-
Wetlands (peat)	Hectare	22,555,000	1.126	-	-
Soil	Hectare	89,119,000	0.063		-
Transport to Stratosphere	Tonnes N2O	260,881	-	-	0.0645
Reaction with OH	Tonnes CH4	564,300	-	1	-
Cultivated Land	Hectare	5,650,000	-	0.01	-

TABLE 4.2
1988 NET CO2 EMISSIONS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

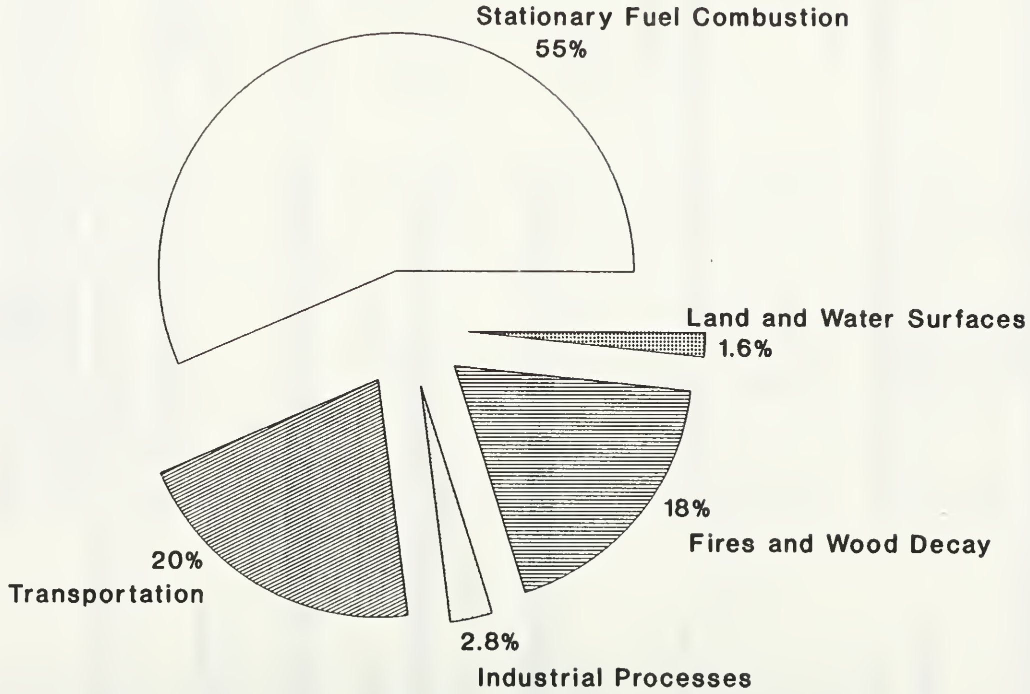
SOURCES	CARBON DIOXIDE	
	(kt)	(%) of total
STATIONARY FUEL COMBUSTION		
Oil Products	19,220	8.57
Natural Gas	41,840	18.65
NGLs	4,147	1.85
Coal	48,809	21.75
Wood/Waste	9,383	4.18
Total	123,400	55.00
TRANSPORTATION		
Motor Gasoline	29,313	13.06
Diesel	9,939	4.43
Aviation Turbo	4,236	1.89
Aviation Gas	76	0.03
Heavy Fuel Oil	784	0.35
Total	44,349	19.77
FOSSIL FUEL PRODUCTION	2,145	0.96
INDUSTRIAL PROCESSES	6,175	2.75
PRODUCT USAGE	1	0.00
INCINERATION	1,854	0.83
LANDFILLS AND SEWAGE TREATMENT	1,792	0.80
FIRES AND WOOD DECAY	41,172	18.35
AGRICULTURE	-	-
LAND AND WATER SURFACES		
Soils	-	-
Wetlands	-	-
Lakes and Reservoirs	-	-
Lightning (over Forests)	-	-
Forest Harvesting	3,484	1.55
Total	3,484	1.55
WILDLIFE	-	-
TOTAL SOURCES	224,372	100.0
SINKS		
Forests	139,200	76.41
Lakes	3,885	2.13
Rivers	8,083	4.44
Wetlands (peat)	25,397	13.94
Soil	5,614	3.08
Transport to Stratosphere	-	-
Reaction with OH	-	-
Cultivated Land	-	-
TOTAL SINKS	182,180	100.0
NET EMISSIONS	42,192	

TABLE 4.2a
1988 NATURAL AND ANTHROPOGENIC CO2 EMISSIONS (in kilotonnes)

SOURCE	**CARBON DIOXIDE**	
	(kt)	**(%)**
ANTHROPOGENIC		
Stationary Fuel Combustion	123,400	55.00
Transportation	44,349	19.77
Fossil Fuel Production	2,145	0.96
Industrial Processes	6,175	2.75
Product Usage	1	0.00
Incineration	1,854	0.83
Landfills and Sewage Treatment	1,792	0.80
Fires and Wood Decay	41,172	18.35
Agriculture	-	-
Forest Harvesting	3,484	1.55
Total Sources	**224,372**	**100.0**
SINKS		
Cultivated Land	-	-
Total Sinks	-	-
NET EMISSIONS	**224,372**	
NATURAL		
Soils	-	-
Wetlands	-	-
Lakes and Reservoirs	-	-
Lightning (over Forests)	-	-
Wildlife	-	-
Total Sources	**0**	
SINKS		
Forests	139,200	76.41
Lakes	3,885	2.13
Rivers	8,083	4.44
Wetlands (peat)	25,397	13.94
Soil	5,614	3.08
Transport to Stratosphere	-	-
Reaction with OH	-	-
Total Sinks	**182,180**	**100.0**
NET EMISSIONS	**(182,180)**	
TOTAL NET EMISSIONS	**42,192**	

FIGURE 4.1

DISTRIBUTION OF THE MAJOR CONTRIBUTORS OF CARBON DIOXIDE BY PERCENT (1988)



Note: Percentages do not add up to 100% because only major contributors are shown

4.2 N_2O

Table 4.3 is a summary of the sources, sinks and net emissions of N_2O, as well as the contribution from each source. Table 4.3a divides the summary into anthropogenic and natural sources, sinks and net emissions. Figure 4.2 illustrates the information contained in Table 4.3. A complete list is provided in Table 6.2. The contribution of emission sources is quite different from the MOE inventory due to the addition of natural sources. As a result, the major source of N_2O is from soils (86%), followed by industrial processes (8%) and stationary fuel combustion (3%).

As mentioned in Section 3.2, the dominant sink for N_2O is photochemical decomposition in the stratosphere and no natural uptake factors were found in the literature. Therefore, assuming a migration rate of 15 years for transport of N_2O from the troposphere to the stratosphere corresponds to a loss of 6.4% (per year) of total emissions or a sink of 16.8 kt.

The net emission of N_2O for Ontario is 244.1 kt.

4.3 CH_4

Table 4.4 contains a summary of the sources, sinks and net emissions of CH_4, as well as the contribution of each source. Table 4.4a divides the summary into anthropogenic and natural sources, sinks and net emissions. Figure 4.3 illustrates the information contained in Table 4.4. A complete list of sources is provided in Table 6.3. The largest contributors of methane emissions are landfills (34%), wetlands (33%) and agriculture (20%). The contribution of wetlands is smaller than that calculated by Jaques (1991) for Canada, due to the difference between the province of Ontario and national wetland coverage, and to the calculation of emissions by wetland region, rather than by wetland type.

The total CH_4 uptake by sinks is estimated to be 1,181 kt, with 48% by reaction with the OH radical, 47% by forest soil and 5% by cultivated land.

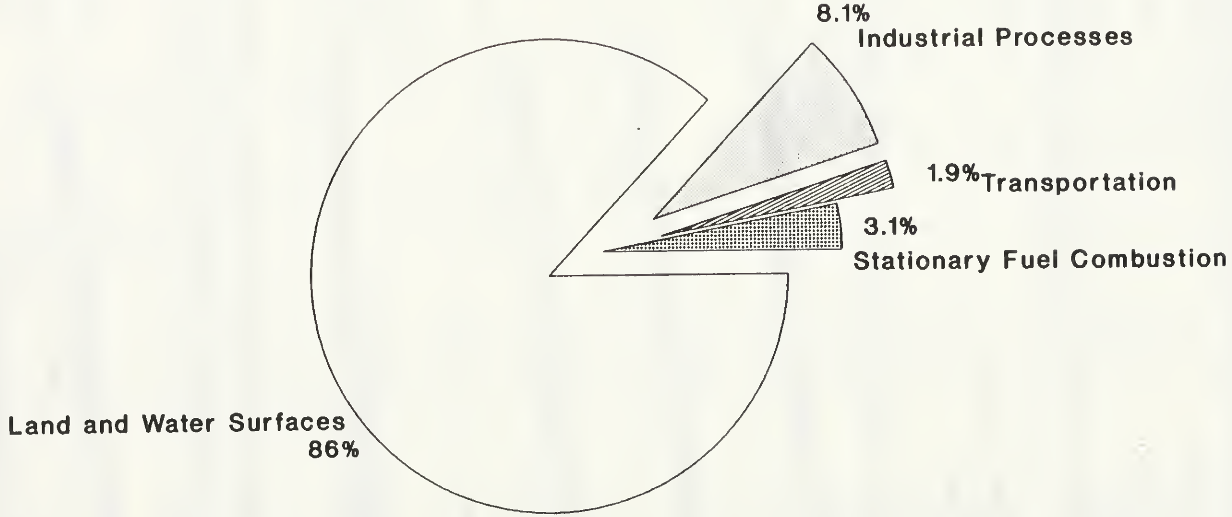
TABLE 4.3
1988 NET N2O EMISSIONS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

SOURCES	NITROUS OXIDE EMISSIONS	
	(kt)	(%) of total
STATIONARY FUEL COMBUSTION		
Oil Products	1.22	0.47
Natural Gas	1.54	0.59
NGLs	0.20	0.08
Coal	3.96	1.52
Wood/Waste	1.05	0.40
Total	7.97	3.06
TRANSPORTATION		
Motor Gasoline	3.07	1.18
Diesel	1.47	0.56
Aviation Turbo	0.36	0.14
Aviation Gas	0.01	0.00
Heavy Fuel Oil	0.03	0.01
Total	4.95	1.90
FOSSIL FUEL PRODUCTION	0.03	0.01
INDUSTRIAL PROCESSES	21.23	8.14
PRODUCT USAGE	0.59	0.23
INCINERATION	0.28	0.11
LANDFILLS AND SEWAGE TREATMEN	-	-
FIRES AND WOOD DECAY	1.41	0.54
AGRICULTURE	1.15	0.44
LAND AND WATER SURFACES		
Soils	222.80	85.40
Wetlands	-	-
Lakes and Reservoirs	-	-
Lightning (over Forests)	0.48	0.18
Forest Harvesting	-	-
Total	223.27	85.58
WILDLIFE	-	-
TOTAL SOURCES	260.9	100.0
SINKS		
Forests	-	
Lakes	-	
Rivers	-	
Wetlands (peat)	-	
Soil	-	
Transport to Stratosphere	16.8	
Reaction with OH	-	
Cultivated Land	-	
TOTAL SINKS	16.8	100.0
NET EMISSIONS	244.1	

ANTHROPOGENIC N2O EMISSIONS (in kilotonnes)

SOURCE	**NITROUS OXIDE**	
	(kt)	**(%)**
ANTHROPOGENIC		
Stationary Fuel Combustion	7.97	21.19
Transportation	4.95	13.16
Fossil Fuel Production	0.03	0.08
Industrial Processes	21.23	56.45
Product Usage	0.59	1.57
Incineration	0.28	0.74
Landfills and Sewage Treatment	-	-
Fires and Wood Decay	1.41	3.75
Agriculture	1.15	3.06
Forest Harvesting	-	-
Total Sources	**37.6**	**100.0**
SINKS		
Cultivated Land	-	-
Total Sinks	-	-
NET EMISSIONS		
	37.6	
NATURAL		
Soils	222.80	99.8
Wetlands	-	-
Lakes and Reservoirs	-	-
Lightning (over Forests)	0.48	0.2
Wildlife	-	-
Total Sources	**223.27**	**100.0**
SINKS		
Forests	-	-
Lakes	-	-
Rivers	-	-
Wetlands (peat)	-	-
Soil	-	-
Transport to Stratosphere	16.80	100.0
Reaction with OH	-	-
Total Sinks	**16.80**	**100.0**
NET EMISSIONS		
	206.5	
TOTAL NET EMISSIONS	**244.1**	

FIGURE 4.2
DISTRIBUTION OF THE MAJOR CONTRIBUTORS OF NITROUS OXIDE BY PERCENT (1988)



Note: Percentages do not add up to 100% because only major contributors are shown

TABLE 4.4
1988 NET CH4 EMISSIONS FOR THE PROVINCE OF ONTARIO (In kilotonnes)

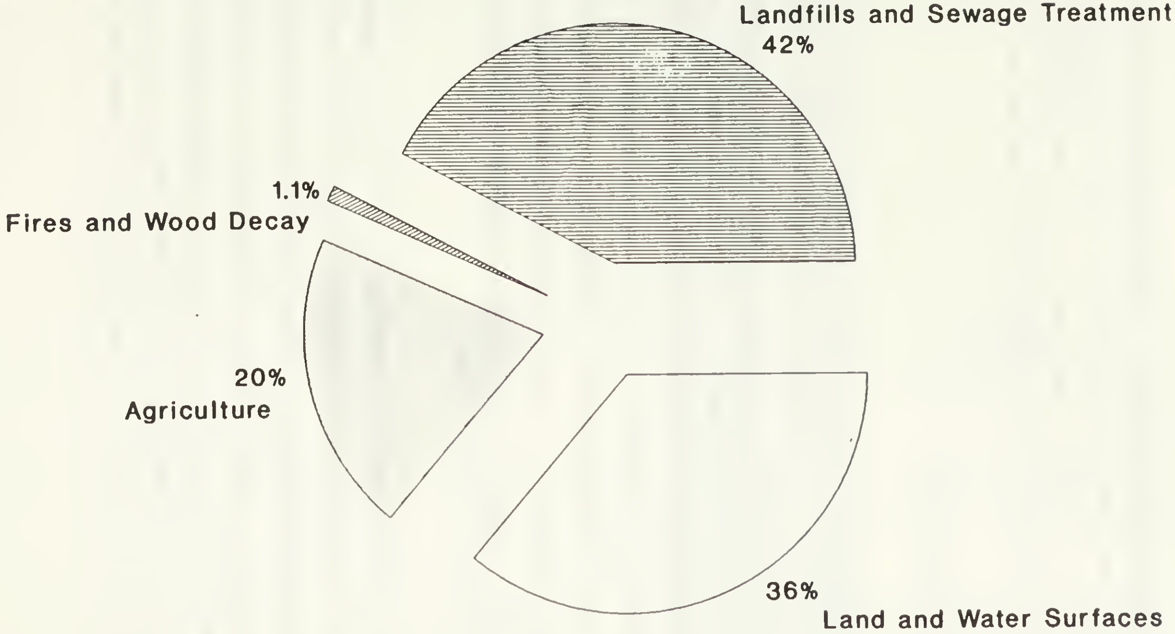
SOURCES	METHANE EMISSIONS (kt)	(%) of total
STATIONARY FUEL COMBUSTION		
Oil Products	0.65	0.04
Natural Gas	0.99	0.06
NGLs	0.10	0.01
Coal	0.35	0.02
Wood/Waste	2.02	0.12
Total	4.10	0.24
TRANSPORTATION		
Motor Gasoline	0.91	0.05
Diesel	0.30	0.02
Aviation Turbo	0.13	0.01
Aviation Gas	0.00	0.00
Heavy Fuel Oil	0.02	0.00
Total	1.35	0.08
FOSSIL FUEL PRODUCTION	0.67	0.04
INDUSTRIAL PROCESSES	-	-
PRODUCT USAGE	-	-
INCINERATION	7.20	0.43
LANDFILLS AND SEWAGE TREATMEN	699.4	41.69
FIRES AND WOOD DECAY	17.64	1.05
AGRICULTURE	338.9	20.2
LAND AND WATER SURFACES		
Soils	-	-
Wetlands	555.6	33.1
Lakes and Reservoirs	42.57	2.54
Lightning (over Forests)	-	-
Forest Harvesting	-	-
Total	598.2	35.7
WILDLIFE	9.89	0.59
TOTAL SOURCES	1,677	100.00
SINKS		
Forests	560.0	47.5
Lakes	-	-
Rivers	-	-
Wetlands (peat)	-	-
Soil	-	-
Transport to Stratosphere	-	-
Reaction with OH	564.3	47.8
Cultivated Land	56.5	4.8
TOTAL SINKS	1,181	100.00
NET EMISSIONS	496.5	

TABLE 4.4a
1988 NATURAL AND ANTHROPOGENIC CH4 EMISSIONS (in kilotonnes)

SOURCE	METHANE	
	(kt)	(%)
ANTHROPOGENIC		
Stationary Fuel Combustion	4.10	0.38
Transportation	1.35	0.13
Fossil Fuel Production	0.67	0.06
Industrial Processes	-	0.00
Product Usage	-	0.00
Incineration	7.20	0.67
Landfills and Sewage Treatment	699.4	65.41
Fires and Wood Decay	17.64	1.65
Agriculture	338.9	31.69
Forest Harvesting	-	-
Total Sources	**1069.3**	**100.0**
SINKS		
Cultivated Land	56.5	-
Total Sinks	**56.5**	**-**
NET EMISSIONS	**1,013**	
NATURAL		
Soils	-	-
Wetlands	555.6	91.3
Lakes and Reservoirs	42.57	7.0
Lightning (over Forests)	0.48	-
Wildlife	9.89	1.6
Total Sources	**608.5**	**100.0**
SINKS		
Forests	560.0	49.8
Lakes	-	-
Rivers	-	-
Wetlands (peat)	-	-
Soil	-	-
Transport to Stratosphere	-	-
Reaction with OH	564.3	50.2
Total Sinks	**1,124**	**100.0**
NET EMISSIONS	**-515.8**	
TOTAL NET EMISSIONS	**496.5**	

FIGURE 4.3

DISTRIBUTION OF THE MAJOR CONTRIBUTORS OF METHANE BY PERCENT (1988)



Note: Percentages do not add up to 100% because only major contributors are shown

Therefore, the 1988 net emission of CH_4 for Ontario is 496.5 kt.

4.4 CFCs

Table 4.5 contains a summary of the 1988 CFC related emissions in the province of Ontario. The emissions total 11.2 kt and the sink is estimated as 0.7 kt (assuming a similar migration rate from the troposphere to the stratosphere as for N_2O) giving a net emission of 10.5 kt.

4.5 OTHER GREENHOUSE GASES

Volatile organic compounds and nitrogen oxides are the primary precursors of tropospheric ozone. Methane and carbon monoxide reactions control the atmospheric concentrations of the OH radical, which in turn control the atmospheric residence time of compounds important to radiative heating of the troposphere (greenhouse effect), and compounds important to ozone chemistry and stratospheric ozone depletion. A product of depleted stratospheric ozone is more intense UV radiation in the troposphere, which drives ozone formation. Ozone, N_2O, CH_4, CF_2CL_2 (Freon-12) and CO_2 also influence the radiative balance of the earth's atmosphere. Increased atmospheric concentrations of these compounds will elevate tropospheric temperature and decrease stratospheric temperature. The temperature changes can influence reaction rates forming and destroying ozone (U.S. EPA, 1988).

Tropospheric O_3 is a greenhouse gas, of particular importance in the upper troposphere of the tropics and subtropics. Its distribution is controlled by a complex interplay between chemical, radiative and dynamic processes. Ozone is: (i) transported down into the troposphere from the stratosphere; (ii) destroyed by vegetative surfaces; (iii) produced by the photo-oxidation of CO, CH_4 and non-methane hydrocarbons NMHC in the presence of reactive nitrogen oxides (NO_x), and (iv) destroyed by uv-photolysis and by reaction with hydrogen oxide radicals (HO_2). Chemical processes in clouds can also have a strong influence on O_3 production and destruction rates.

TABLE 4.5

1988 NET CFC EMISSIONS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

SOURCE	CFC-11	CFC-12	CFC-113	TOTAL
Fugitive Production Emissions	-	0.67	0.14	0.81
Refrigeration	0.40	1.94	1.30	3.64
Open Cell Foam	0.17	1.07	-	1.24
Closed Cell Foam	2.17	0.51	0.58	3.25
Solvent	-	-	1.11	1.11
Aerosol	-	0.81	-	0.81
Miscellaneous	-	-	0.30	0.30
TOTAL ONTARIO EMISSIONS	**2.73**	**5.00**	**3.43**	**11.17**
SINK				**0.72**
NET EMISSION				**10.45**

Consequently, while CO, NMHC and NO_x are not important greenhouse gases in themselves, they are important precursors of tropospheric O_3.

Atmospheric Distribution

Ozone in the troposphere has a lifetime of, at most, several weeks, hence its concentration varies with latitude, longitude, altitude and season. Near the surface, monthly mean concentrations are highest in spring and summer at northern mid-latitudes. In the middle troposphere at northern mid-latitudes, values are also highest in spring and summer. The summer maximum results from photo-oxidation of O_3 precursors from fossil fuel combustion and industrial activity.

Most long-term measurements of O_3 have been made at northern mid-latitudes, from surface sites and from balloons. A comparison of data obtained in Paris from 1876-1910 (Volz and Kley, 1988 as cited by Houghton et al., 1990) with rural data from the present day from Europe and North America (Logan, 1985, 1989, as cited by Houghton et al., 1990) suggests that surface O_3 has increased by a factor of 2 to 3 on average; the increase being largest in summer, by a factor of 4 to 6.

The ground-based, direct sun, total ozone measurements made at Toronto between 1960 and 1991 were analyzed by Kerr (1991). Ozone decreased over Toronto by 4.2% during the 1980s. These results confirm the Total Ozone Mapping Spectrometer (TOMS) satellite measurements for the mid-latitude Northern Hemisphere (NH), and indicate that the behaviour of ozone at Toronto is reasonably representative of that averaged over the entire mid-latitude NH.

In addition to being a strong absorber of ultraviolet light, ozone (O_3) also absorbs infrared radiation in the atmospheric window and is therefore an important Greenhouse gas. Its contribution, on a molecule-for-molecule basis is 2,000 as great as CO_2. The contribution of ozone to the enhanced greenhouse effect caused by human activity is roughly 8%. The considerable uncertainty in this figure is due to the fact that ozone differs from the other greenhouse gases in two very important ways. Its lifetime in the lower atmosphere is about 1 month compared to tens to hundreds of years for the other greenhouse gases. This means a few tens of parts per billion in relatively remote areas, to hundreds of parts per billion in polluted areas. The other difference is that, unlike the other gases, ozone is not emitted directly into the atmosphere. It is a secondary pollutant, formed as a result of chemical reactions among other primary pollutants.

It is important to distinguish between ozone in the stratosphere and in the troposphere. In the stratosphere, ozone is formed by the dissociation of molecular oxygen by very short wavelength radiation and destroyed by reactions with free radicals and atoms. The stratospheric ozone layer is decreasing because of the additional destruction processes resulting from the emissions of anthropogenic gases, notably the chlorofluorocarbons (CFC) but also nitrous oxide. The concern is mainly about the resulting increase in the damaging ultraviolet radiation reaching the surface of the earth. The greenhouse effect of O_3, in the stratosphere, like that of the other greenhouse gases, is opposite to that in the troposphere - increases in concentrations lead to cooling, and decreases lead to heating. It is not entirely clear what effect such changes in the stratospheric climate might have on the tropospheric climate or surface temperature. The coupling between the stratospheric and the tropospheric climate is not well understood. The most likely coupling involves changes in the tropospheric circulation patterns.

In contrast, ozone concentrations in the lower atmosphere (the troposphere) are increasing in the Northern Hemisphere at the rate of more than 1% per year (but not enough to compensate for the decrease in stratospheric ozone as far as the ultraviolet radiation is concerned). Since the short wavelength radiation which produces O_3 in the stratosphere cannot penetrate into the troposphere, it was believed until recently that most of the O_3 found in the troposphere was being transported down from the stratosphere. It is now believed, however, that most of the O_3 found in the Northern Hemisphere is made in the troposphere by the action of visible sunlight on the primary pollutants, nitrogen oxides (NO_x) and hydrocarbons.

The dependence of ozone production on the precursor pollutants is highly non-linear. At low NO_x concentrations, there is an excess of hydrocarbons and ozone destruction can occur. At very high ratios of NO_x to hydrocarbons, as occurs during photochemical smog periods in Toronto in the summer, additional NO_x emission can lead to O_3 destruction in the city but to O_3 formation downwind in the rural areas. Since O_3 production also depends on light intensity, concentrations show strong seasonal and diurnal variations. During the day they are considerably higher than at night, although this variation also depends on local meteorological conditions, such as the existence of a nocturnal inversion layer. The concentration of O_3 generally peaks in the summer in the Northern Hemisphere.

In remote areas, O_3 levels in the 10-20 ppbv levels are observed. However, in many urban and rural areas in North America levels ten times these values are frequently observed. Serious health and crop damage effects can occur at these levels which has led the Canadian Council of Ministers of the Environment (CCME) to recommend standards of less than 82 ppbv for hourly O_3 levels. Exceedences of this figure occur frequently in the Windsor-Quebec corridor which has designated a priority region in the CCME action plan. Although many of the precursors for O_3 production in this corridor are the result of emissions in Ontario, O_3 and its precursors also are imported from the U.S.A. The lifetime of O_3 and its precursors are long enough for the transboundary journey.

In addition to its direct contribution to the greenhouse effect, O_3 also affects the concentration of the second most important greenhouse gas, methane. The main loss process for methane is reaction with the concentration of hydroxyl radicals (OH), which is directly related to the amount of O_3 in the atmosphere.

4.6 UNCERTAINTY

Emission factors and methodologies were adapted from Environment Canada (Jaques, 1990; 1991) and the OECD (1991), where available and all other emission and uptake factors were taken from other literature sources (rating factors between A and E were assigned to average values).

When searching through the literature, a database was created (RANGES.DBF, which is included on Disk #3) when emission or uptake factors were reported as ranges rather than single values.

Therefore, a range was calculated in order to indicate the uncertainty associated with the mean or median value.

There is a large spread in these uncertainty ranges. For example while the relative uncertainty of emissions from combustion sources may be 25%, reported wetland emissions range over several orders of magnitude. Therefore, it is difficult to estimate the overall uncertainty of emissions, particularly for natural sources.

Tables 4.6, 4.7 and 4.8 (for CO_2, N_2O and CH_4, respectively) list the overall estimated uncertainty range for each major source and sink category. These estimates are based on reported ranges in the literature, as well as on the expected uncertainty ranges of the emission factors chosen for the inventory. These estimated ranges are then applied to the 1988 inventory emissions and sinks to determine the overall range of uncertainty, associated with CO_2, CH_4 and N_2O.

CFCs are not included in Tables 4.6, 4.7 and 4.8 because of the nature of the simplifying assumptions used to estimate emissions (see Section 2.4). SENES expects the estimated net CFC emissions to fall within an order of magnitude of the calculated values.

Table 4.6

ESTIMATED UNCERTAINTY RANGES FOR CO_2 EMISSIONS (kilotonnes)

Source	Uncertainty (%)	Range		
Stationary fuel combustion	25	123,400	±	30,850
Transportation	25	44,349	±	11,087
Fossil fuel production	25	2,145	±	536
Industrial processes	20	6,175	±	1,235
Product usage	30	1	±	0.3
Incineration	50	1,854	±	927
Landfills & Sewage Treatment	75	1,792		1,344
Fires & Wood Decay	75	41,172	±	30,879
Agriculture	-		±	-
Land & Water Surfaces	30	3,484	±	1,045
Wildlife	-			
OVERALL UNCERTAINTY	20	224,372	±	45,097
Sinks				
Forests	40	139,200	±	55,680
Lakes	60	3,885	±	2,331
Rivers	30	8,083	±	2,425
Wetlands	30	25,397	±	7,619
Soil	85	5,614	±	4,712
Transport to Stratosphere	-			-
Reaction with OH radical	-			-
Cultivated Land				-
OVERALL UNCERTAINTY	31	182,180	±	56,496

Table 4.7

ESTIMATED UNCERTAINTY RANGES FOR N_2O EMISSIONS (tonnes)

Source	Uncertainty (%)	Range		
Stationary fuel combustion	30	7,970	±	2,391
Transportation	30	4,949	±	1,485
Fossil fuel production	25	25.2	±	6.3
Industrial processes	20	21,232	±	4,246
Product usage	30	591.8	±	177.5
Incineration	50	281.7	±	140.9
Landfills & Sewage Treatment	-			-
Fires & Wood Decay	75	1,411	±	1,058
Agriculture	80	1,150	±	920
Land & Water Surfaces	90	223,274	±	167,455
Wildlife	-			
OVERALL UNCERTAINTY	64	260,884	±	167,538
Sinks				
Forests	-			
Lakes	-			
Rivers	-			
Wetlands	-			
Soil	-			
Transport to Stratosphere	30	16,830	±	5,049
Reaction with OH radical	-			
Cultivated Land				
OVERALL UNCERTAINTY	30	16,830	±	5,049

Table 4.8

ESTIMATED UNCERTAINTY RANGES FOR CH_4 EMISSIONS (tonnes)

Source	Uncertainty (%)	Range		
Stationary fuel combustion	35	4,103	±	1,436
Transportation	35	1,352	±	473.2
Fossil fuel production	25	667.5	±	166.9
Industrial processes	-		±	-
Product usage	-		±	-
Incineration	50	7,196	±	3,598
Landfills & Sewage Treatment	50	699,404		349,702
Fires & Wood Decay	50	17,638	±	8,819
Agriculture	30	338,917	±	101,675
Land & Water Surfaces	75	598,153	±	448,615
Wildlife	30	9,888		2,966
OVERALL UNCERTAINTY	34	1,677,318	±	577,916
Sinks				
Forests	50	560,000	±	280,000
Lakes	-			
Rivers	-			
Wetlands	-			
Soil	-			
Transport to Stratosphere	-			
Reaction with OH radical	90	564,300	±	507,870
Cultivated Land	90	56,500	±	50,850
OVERALL UNCERTAINTY	49	1,180,800	±	582,166

5.0 GREENHOUSE GAS FORECAST METHODOLOGY

5.1 GENERAL

The base forecast assumes no change in government policy that affects the long term trend in emissions of greenhouse gases. Specific policy commitments, such as the phase-out of CFCs and the reduction in solid waste sent to landfills, are explicitly addressed.

5.2 ENERGY-RELATED EMISSIONS

The forecast of energy-related emissions of greenhouse gases is based on a forecast of Ontario energy demand developed using information provided by the Ministry of Energy. The Ministry provided data on actual energy demand by end use and fuel type for 1988, 1989 and 1990. The Ministry also provided forecast energy demand for 1991, 1995, 2000 and 2005. The historic information is understandably more detailed than the forecast. For example, the historic data divide residential petroleum product demand into light fuel oil, heavy fuel oil and kerosene while the forecast shows only total petroleum product demand for the residential sector.

The actual data are used for the years 1988 through 1990. Future years are forecast by applying the **growth rates** from the energy demand forecast to the 1990 base year. On the advice of the Ministry of Energy the growth rates rather than the forecast values are used because the forecast was developed with an earlier base year. The growth rates for the 2000-2005 period in the energy demand forecast were assumed to prevail for the decade to 2010.

Where the historic detail is greater than the forecast, the historic mix of products is assumed to remain unchanged over the forecast period. In the example, residential demand for petroleum products is assumed to consist of 93.5% light fuel oil, 0.5% heavy fuel oil, and 6.0% kerosene. This is equivalent to applying the same growth rate to each product category.

The London regional office of the Ministry of Natural Resources indicated that oil production in Ontario was approximately constant and that natural gas production was declining at a rate of about 5% per year.

These growth rates are used to forecast production of oil and natural gas in Ontario as the basis for projecting production-related emissions of greenhouse gases. The volume of natural gas transported within Ontario is forecast to rise at the same rate as the growth in demand for natural gas in the province. Raw CO_2 emissions were based on the forecast of natural gas production since the emission is based on this parameter.

Ontario Hydro's Demand/Supply Plan Update-1992 includes revised projections of CO_2 emissions. The CO_2 emissions for three options: fossil, nuclear and enhanced are provided in Table 5.1. The emissions for the fossil and nuclear options are identical from 1995 through 2009.

5.3 INDUSTRIAL PROCESSES AND PRODUCT USAGE

Various industrial processes give rise to emissions of greenhouse gases. The forecast production level for each of these processes is determined as follows:

- Cement Manufacturing. A forecast of cement production with annual values for the period 1980 through 2010 provided by the Ministry of Energy was used for the period 1989 through 2010.

- Lime Manufacturing. An Ontario Hydro forecast of lime production was used (Load Forecasts Department, 1990. "Physical Units Forecast", File No. 706.01 (#344) August, page 43).

- Kraft Pulp and Paper. The annual growth rate for Ontario GDP in the pulp and paper industry as forecast by the Ministry of Energy for the period 1989 through 2010 were applied to the 1988 base value.

Table 5.1

ONTARIO HYDRO CO_2 EMISSIONS (Tg)

	Fossil Option	Nuclear Option	Enhanced
1995	-	20.8	19.1
1996	-	20.5	20.4
1997	-	18.1	17.1
1998	-	20.4	17.7
1999	-	17.1	12.6
2000	-	14.6	8.8
2001	-	14.9	8.1
2002	-	15.5	8.1
2003	-	19.3	10.3
2004	-	20.3	11.3
2005	-	20.9	13.1
2006	-	20.4	14.1
2007	-	17.0	12.5
2008	-	17.9	14.4
2009	-	18.9	16.5
2010	21.8	18.2	21.4
2011	33.9	26.8	33.7
2012	38.8	27.5	38.4
2013	43.4	24.3	40.5
2014	45.1	22.8	42.4

Source: Ontario Hydro, 1992. Data for Figures of Exhibit 452, Demand/Supply Plan Update - 1992, January, page 23.

- Coke Production. Since the electric are furnace is becoming more common for steel production, constant or declining emissions due to coke production are expected to occur. In the absence of specific information, a constant 2% annual reduction was assumed.

- Ammonia Production. The forecast of ammonia production is taken from the forecast provided by the Ministry of Energy.

- Nitric Acid Production. Since one of the major demands for both nitrogen and nitric acid is to produce nitrogen fertilizers, the growth rate for nitrogen production prepared by Ontario Hydro is used to forecast nitric acid production.

- Adipic Acid Production. One of the major uses of adipic acid is nylon production. DuPont Canada announced (6 March, 1991) that it intends to eliminate nitrous oxide emissions from adipic acid production within the next five years. Therefore, N_2O emissions were assumed to be constant until 1996, and zero thereafter.

Use of N_2O (as an anaesthetic and a propellant) are all forecast to grow at the same rate as the population.

Canadian production of CFCs is forecast to decline from 20,300 tonnes in 1988 to 100 tonnes in the year 2000 and then remain constant at that level through to the year 2010. More detail on the CFC forecast is provided in Section 5.7.

5.4 INCINERATION, LANDFILLS AND SEWAGE TREATMENT SOURCES

In April 1991, the Ontario Minister of the Environment banned the construction of new garbage incinerators in Ontario. The Certificates of Approval and monitoring requirements for Ontario's five existing incinerators are being reviewed by the Environment Ministry to determine where they need to be upgraded. It is assumed that the volume of municipal waste incinerated remains constant and that the rest is landfilled. The volumes of sewage sludge, industrial waste, and commercial/institutional waste incinerated and sawdust incinerated in wigwam burners are all assumed to remain constant because SENES could not find any information on forecast volumes of incineration.

A forecast of municipal waste was developed after consultations with the Ministry of the Environment. The assumed waste reduction goals (25% by the year 1992 and 50% by 2000) are the MOE's Waste Diversion Objectives, and are minimum values. Therefore, if further reduction is achieved, landfill emissions may be overestimated. The quantity of municipal waste incinerated is subtracted and the rest is assumed to be landfilled. The quantity of municipal waste sent to landfills is input to the landfill gas model that forecasts the volumes of CO_2 and CH_4 that will be generated (see Sections 2.1.2.6 and 2.3.2.1). The volumes of CO_2 and CH_4 from the model are used as the forecast.

The quantity of methane released from sewage treatment plants is forecast to grow at the same rate as the population.

5.5 EMISSIONS FROM FIRES, WOOD DECAY, LAND AND WATER SURFACES AND WILDLIFE

Emissions from structural fires, prescribed fires, forest fires, land and water surfaces, and wildlife are assumed to remain constant over the forecast period. The emissions due to wood decay are forecast to increase at the same rate as the population.

5.6 LIVESTOCK AND FERTILIZER USE

Statistics Canada (Agriculture Economic Statistics, 21-603) provides an index of farm production by province for the period 1935 through 1985, an index of livestock and animal products production and an index of crop production by province for the period 1951 through 1985. It was assumed that the index of crop production and the index of livestock production, each appropriately weighted, gives the index of farm production. The weights of crop production and livestock production were calculated for Ontario for the period 1951 through 1985. The weight of crop production and livestock production were found to average 32.75% and 62.75%, respectively. Although these weights varied over the period, there was no long term trend. Hence the number of livestock and fertilizer use (i.e. N_2O emissions from fertilized soil) are forecast to grow at the same rate as real GDP in agriculture in Ontario. The forecast of real GDP in agriculture is drawn from the PRISM model economic forecast prepared for the Ministry of Energy.

5.7 FORECAST OF CANADIAN PRODUCTION OF CFCs

Both Canada and Ontario have committed to phase out the use of CFCs, except in essential uses, by 2000. Actual use of CFCs in Canada fell from 20,300 tonnes in 1988 to 17,400 tonnes in 1989, a drop of 2,900 tonnes. Canadian production of CFCs is forecast to drop by 2,000 tonnes per year from 17,400 tonnes in 1989 to 1,400 tonnes in 1997. Production is forecast at 700 tonnes in 1998, 400 tonnes in 1999 and 100 tonnes in 2000. The 100 tonnes is assumed to cover essential uses and is assumed to remain constant through 2010.

The mix of CFCs produced is assumed to remain the same as in the base year, namely 26% of CFC-11, 42% of CFC-12, and 32% of other CFCs. Total Canadian production of CFCs and the mix of CFCs produced are inputs to the FORECAST spreadsheet. The quantity of each type of CFC produced in Canada over the forecast period is calculated by that spreadsheet and transferred to the spreadsheet CFCS. This information appears in rows 12 through 16 of CFCS.

Forecast Use of CFCs in Ontario

Ontario is assumed to consume 50% of the Canadian production of CFCs. As production declines, each CFC is assumed to be phased out of some uses before others. CFC-11 is assumed to be displaced first from the production of open cell foams, then from closed cell foams, and finally from refrigeration applications. CFC-12 is assumed to be eliminated from aerosols, then, closed cell foams, open cell foams and finally refrigeration. Other CFCs are replaced first in miscellaneous applications, then as solvents, in closed cell foams and finally in refrigeration.

Ontario consumption of each type of CFC is calculated in rows 18 through 21 of CFCS. The quantity of each type of CFC used in each application in Ontario is calculated in rows 23 through 39 of CFCS.

5.8 SINKS

Greenhouse gas uptakes by lakes, rivers and wetlands were assumed to remain constant over the entire forecast period. Changes in uptake factors due to forestry and agricultural practices are described below. A quick estimation by the Forest Policy Branch, Ministry of Natural Resources (G. Doan, 1992) was used to forecast the net change in forest growth to the year 2010. For the purposes of this estimate, the far north of the province (covering about 40 million hectares) is assumed to continue in a steady state, with no net change in wood stored during the period. This assumption could prove invalid if forest fire protection is extended to the area.

The productive forest covers 40 million hectares. The duff layer of organic material, which is important in the carbon storage process, is assumed to remain at present levels, with additions from leaves and dying plants being matched by oxidation. Therefore, the uptake of CO_2 and CH_4 by forests were based on the net growth of forests from 1988 to 2010 (growth rate minus harvest minus fire, insect and disease losses).

Carbon is sequestered in plants and soils. Plant growth absorbs carbon while decay releases carbon. Long lived species, such as trees, can be managed to increase the amount of carbon sequestered. Once absorbed by the tree, the carbon is effectively sequestered until the tree starts to decay. Some carbon is organically bound in the soil. Research into means of increasing the amount of carbon in the soil, or of reducing the release of organically bound carbon is currently underway.

Agricultural crops grow and decay within the space of a year. Thus to sequester carbon for long periods of time (decades) using agricultural practices is much more complex than for forestry. Research into possible means of using agricultural practices for carbon storage in soils is underway (for example at University of Guelph). At the moment not enough is known about the appropriate practices to speculate on the quantities that could be sequestered. Changes in agricultural practices to increase carbon storage will probably require government initiatives. As a base forecast, no change in carbon sequestration due to agricultural practices is appropriate.

6.0 FORECAST EMISSIONS OF GREENHOUSE GASES

Tables 6.1, 6.2, 6.3 and 6.4 list present and future CO_2, N_2O, CH_4 and CFC emissions (in kilotonnes).

6.1 CARBON DIOXIDE

Net emissions of carbon dioxide in Ontario are forecast to grow from 42,192 kilotonnes in 1988 to 134,726 kilotonnes in 2010. Apart from the forest sector (which eventually decreases), sequestration of carbon by natural sinks is forecast to remain fairly constant, so the growth in net emissions is mostly due to increasing emissions.

6.2 NITROUS OXIDE

Net emissions of nitrous oxide in Ontario are forecast to decrease from 244.1 kilotonnes (70.8 kilotonnes of CO_2 equivalent) in 1988 to 236.6 kilotonnes (68.6 kilotonnes of CO_2 equivalent) in 2010. This is due to decreasing emissions, particularly with the phase-out of N_2O emissions from adipic acid production.

6.3 METHANE

Net emissions of methane in Ontario are forecast to grow from 496.5 kilotonnes (10,427 kilotonnes of CO_2 equivalent) in 1988 to 754.0 kilotonnes (15,835 kilotonnes of CO_2 equivalent) in 2010. This is due to increased emissions, and a slight decline in CH_4 uptake by forest soils.

6.4 CFCs

Net emissions of CFCs in Ontario are forecast to decline from 11.2 kilotonnes in 1988 to 0.7 kilotonnes in 2010. By the end of the period, only 100 tonnes of CFCs are forecast to be produced annually in Canada, but emissions in Ontario are much higher due of the stock of CFCs

TABLE 6.1
PRESENT AND FUTURE CARBON DIOXIDE EMISSIONS (kilotonnes)

	YEAR					
SOURCES	**1988**	**1990**	**1995**	**2000**	**2005**	**2010**
OIL PRODUCTS						
RESIDENTIAL						
Total	**4,475**	**3,961**	**3,446**	**3,277**	**2,829**	**2,442**
LFO	4,197	3,729	3,236	3,078	2,657	2,293
HFO	15	22	18	17	14	12
Kerosene	264	210	192	183	158	136
COMMERCIAL						
Total	**1,422**	**1,306**	**1,150**	**1,013**	**973**	**935**
LFO	1,082	1,075	921	812	780	749
HFO	252	170	175	154	148	142
Kerosene	88	61	53	47	45	43
INDUSTRIAL						
Total	**6,830**	**6,272**	**6,815**	**7,487**	**8,389**	**9,399**
LFO Construction	95	88	94	104	116	130
LFO Mining	29	22	27	30	33	37
LFO Other	22	29	27	30	33	37
HFO Agriculture	7	0	7	8	8	9
HFO Construction	7	0	7	8	8	9
HFO Chemicals	999	488	751	826	925	1,036
HFO Iron + Steel	1,080	992	1,059	1,163	1,303	1,460
HFO Mining	192	170	184	203	227	254
HFO Cement	37	22	27	30	34	38
HFO Pulp + Paper	363	222	301	330	370	415
HFO Other	533	1,006	813	893	1,001	1,121
Kerosene	14	14	12	14	15	17
Diesel Agriculture	679	679	718	789	884	990
Diesel Construction	643	763	731	803	900	1,008
Diesel Chemicals	7	7	7	7	8	9
Diesel Iron + Steel	49	71	65	72	80	90
Diesel Mining	254	254	261	287	321	360
Diesel Pulp + Paper	141	127	137	151	169	189
Diesel Other	353	21	170	186	209	234
Gasoline Agriculture	625	639	659	724	811	909
Gasoline Other	122	34	69	76	85	95
Petroleum Coke Mining	132	113	122	134	150	168
Petroluem Coke Cement	349	453	488	536	601	673
Petroleum Coke Other	94	57	78	86	97	108
TRANSPORTATION						
Total	**44,349**	**43,028**	**46,996**	**49,638**	**53,211**	**57,042**
Motor Gasoline	29,313	28,756	31,377	33,141	35,526	38,084
Diesel	9,939	9,571	10,265	10,842	11,623	12,460
Aviation Turbo	4,236	3,620	4,250	4,489	4,812	5,159
Aviation Gas	76	104	95	100	107	115
Heavy Fuel Oil	784	977	1,009	1,066	1,142	1,225
OWN USES AND LOSSES	6,017	6,010	6,072	6,067	6,469	6,897
ELECTRICITY GENERATION	476	1,135	898	1,357	1,454	1,558

TABLE 6.1
PRESENT AND FUTURE CARBON DIOXIDE EMISSIONS (kilotonnes)

YEAR

SOURCES	1988	1990	1995	2000	2005	2010
NATURAL GAS						
Total	**41,840**	**40,971**	**45,725**	**49,991**	**54,655**	**59,755**
Residential	12,594	12,534	13,855	15,147	16,561	18,106
Commercial	7,566	7,397	8,276	9,048	9,893	10,816
Industrial	16,807	16,375	18,244	19,946	21,807	23,842
Transportation	25	40	46	50	55	60
Non-Energy	1,495	969	1,463	1,600	1,749	1,912
Own Uses and Losses	2,926	3,239	3,384	3,699	4,044	4,422
Electricity Generation	427	417	457	500	547	598
NGLs						
Total	**4,147**	**3,441**	**3,663**	**3,850**	**4,147**	**4,468**
Residential	180	168	183	192	207	223
Commercial	245	299	315	331	357	384
Industrial	874	640	758	797	859	925
Transportation	730	646	645	678	730	786
Non-Energy	2,118	1,628	1,744	1,833	1,974	2,127
Own Uses and Losses	0	60	18	19	21	22
COAL						
Total	**48,809**	**39,884**	**48,756**	**55,975**	**62,410**	**69,583**
CANADIAN BITUMINOUS						
Industrial	3,073	0	1,669	1,916	2,136	2,382
Electricity Generation	6,521	7,700	7,863	9,028	10,065	11,222
U.S. BITUMINOUS						
Industrial	14,098	13,830	15,328	17,598	19,621	21,876
Electricity Generation	21,887	16,198	20,910	24,006	26,765	29,842
LIGNITE						
Electricity Generation	3,230	2,157	2,986	3,428	3,822	4,261
WOOD/WASTE						
Total	**9,383**	**8,465**	**10,286**	**10,599**	**10,921**	**11,252**
Residential	1,549	1,549	1,765	1,819	1,874	1,931
Industrial	7,753	6,615	8,298	8,550	8,809	9,077
Electricity Generation	81	301	224	230	237	245
FOSSIL FUEL PRODUCTION						
Natural Gas Production	36	32	25	19	15	12
Natural Gas Transportation	2,049	2,008	2,241	2,451	2,679	2,929
Oil Production	61	61	61	61	61	61
INDUSTRIAL PROCESSES						
Total	**6,175**	**5,418**	**6,121**	**7,057**	**7,814**	**8,510**
Cement Manufacturing	2,720	2,751	3,161	3,676	4,040	4,357
Lime Manufacturing	1,418	1,417	1,570	1,707	1,854	2,007
Kraft Pulp and Paper	441	452	509	609	666	731
Ammonia Production	1,596	798	881	1,065	1,255	1,415
Nitric Acid Production	0	0	0	0	0	0
Adipic Acid Production	0	0	0	0	0	0
PRODUCT USAGE						
Raw CO2	1	1	0	0	0	0
N2O Anaesthetic	0	0	0	0	0	0
N2O Propellant	0	0	0	0	0	0

TABLE 6.1
PRESENT AND FUTURE CARBON DIOXIDE EMISSIONS (kilotonnes)

SOURCES	YEAR 1988	1990	1995	2000	2005	2010
INCINERATION						
Municipal Waste	721	721	721	721	721	721
Sewage Sludge	153	158	172	183	193	203
Industrial Waste	118	118	118	118	118	118
Commercial/Institutional Waste	12	12	12	12	12	12
Wigwam Burners	850	850	850	850	850	850
LANDFILLS AND SEWAGE TREATMENT						
Landfills	1,792	1,969	2,176	2,266	2,310	2,356
Sewage Treatment Plants	0	0	0	0	0	0
FIRES AND WOOD DECAY						
Structural Fires	215	215	215	215	215	215
Prescribed Fires	133	133	133	133	133	133
Forest Fires	12,617	12,617	12,617	12,617	12,617	12,617
Wood Product Decay	28,208	29,106	31,697	33,811	35,536	37,349
AGRICULTURE						
LIVESTOCK						
Cattle	0	0	0	0	0	0
Sheep	0	0	0	0	0	0
Swine	0	0	0	0	0	0
Turkeys	0	0	0	0	0	0
Horses	0	0	0	0	0	0
Goats	0	0	0	0	0	0
Chickens	0	0	0	0	0	0
MANURE						
Cattle	0	0	0	0	0	0
Sheep	0	0	0	0	0	0
Swine	0	0	0	0	0	0
Turkeys	0	0	0	0	0	0
Horses	0	0	0	0	0	0
Goats	0	0	0	0	0	0
Chickens	0	0	0	0	0	0
Fertilizer Use	0	0	0	0	0	0
LAND AND WATER SURFACES						
Soils	0	0	0	0	0	0
Wetlands	0	0	0	0	0	0
Lakes and Reservoirs	0	0	0	0	0	0
Lightning (over Forests)	0	0	0	0	0	0
Forest Harvesting	3,484	3,878	5,068	6,624	8,657	11,314
WILDLIFE						
Moose	0	0	0	0	0	0
Deer	0	0	0	0	0	0
Caribou	0	0	0	0	0	0
TOTAL SOURCES	**224,372**	**211,769**	**236,034**	**256,391**	**277,387**	**300,728**

TABLE 6.1
PRESENT AND FUTURE CARBON DIOXIDE EMISSIONS (kilotonnes)

YEAR

SOURCES	1988	1990	1995	2000	2005	2010
SINKS						
Forests	139,200	137,645	133,834	130,129	126,526	123,022
Lakes	3,885	3,885	3,885	3,885	3,885	3,885
Rivers	8,083	8,083	8,083	8,083	8,083	8,083
Wetlands (peat)	25,397	25,397	25,397	25,397	25,397	25,397
Soil	5,614	5,614	5,614	5,614	5,614	5,614
Transport to Stratosphere	0	0	0	0	0	0
Reaction with OH	0	0	0	0	0	0
Cultivated Land						
TOTAL SINKS	**182,180**	**180,625**	**176,814**	**173,108**	**169,505**	**166,002**
NET EMISSIONS	**42,192**	**31,144**	**59,220**	**83,283**	**107,882**	**134,726**

Note: Bolded totals that do not match the actual totals are a result of round-off error

TABLE 6.2
PRESENT AND FUTURE NITROUS OXIDE EMISSIONS (kilotonnes)

			YEAR			
SOURCES	**1988**	**1990**	**1995**	**2000**	**2005**	**2010**
OIL PRODUCTS						
RESIDENTIAL						
Total	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**
LFO	0.2	0.2	0.2	0.1	0.1	0.1
HFO	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	0.0	0.0	0.0	0.0	0.0	0.0
COMMERCIAL						
Total	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
LFO	0.1	0.1	0.0	0.0	0.0	0.0
HFO	0.1	0.1	0.1	0.1	0.1	0.0
Kerosene	0.0	0.0	0.0	0.0	0.0	0.0
INDUSTRIAL						
Total	**0.6**	**0.5**	**0.6**	**0.6**	**0.7**	**0.8**
LFO Construction	0.0	0.0	0.0	0.0	0.0	0.0
LFO Mining	0.0	0.0	0.0	0.0	0.0	0.0
LFO Other	0.0	0.0	0.0	0.0	0.0	0.0
HFO Agriculture	0.0	0.0	0.0	0.0	0.0	0.0
HFO Construction	0.0	0.0	0.0	0.0	0.0	0.0
HFO Chemicals	0.0	0.0	0.0	0.0	0.0	0.0
HFO Iron + Steel	0.0	0.0	0.0	0.1	0.1	0.1
HFO Mining	0.0	0.0	0.0	0.0	0.0	0.0
HFO Cement	0.0	0.0	0.0	0.0	0.0	0.0
HFO Pulp + Paper	0.0	0.0	0.0	0.0	0.0	0.0
HFO Other	0.0	0.0	0.0	0.0	0.0	0.1
Kerosene	0.0	0.0	0.0	0.0	0.0	0.0
Diesel Agriculture	0.1	0.1	0.1	0.1	0.1	0.1
Diesel Construction	0.1	0.1	0.1	0.1	0.1	0.1
Diesel Chemicals	0.0	0.0	0.0	0.0	0.0	0.0
Diesel Iron + Steel	0.0	0.0	0.0	0.0	0.0	0.0
Diesel Mining	0.0	0.0	0.0	0.0	0.0	0.1
Diesel Pulp + Paper	0.0	0.0	0.0	0.0	0.0	0.0
Diesel Other	0.1	0.0	0.0	0.0	0.0	0.0
Gasoline Agriculture	0.1	0.1	0.1	0.1	0.1	0.1
Gasoline Other	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum Coke Mining	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum Coke Cement	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum Coke Other	0.0	0.0	0.0	0.0	0.0	0.0
TRANSPORTATION						
Total	**4.9**	**4.8**	**5.2**	**5.5**	**5.9**	**6.3**
Motor Gasoline	3.1	3.0	3.3	3.5	3.7	4.0
Diesel	1.5	1.4	1.5	1.6	1.7	1.8
Aviation Turbo	0.4	0.3	0.4	0.4	0.4	0.4
Aviation Gas	0.0	0.0	0.0	0.0	0.0	0.0
Heavy Fuel Oil	0.0	0.0	0.0	0.0	0.1	0.1
OWN USES AND LOSSES	0.3	0.3	0.3	0.3	0.3	0.3
ELECTRICITY GENERATION	0.0	0.1	0.0	0.1	0.1	0.1

TABLE 6.2
PRESENT AND FUTURE NITROUS OXIDE EMISSIONS (kilotonnes)

	YEAR					
SOURCES	1988	1990	1995	2000	2005	2010
NATURAL GAS						
Total	**1.5**	**1.5**	**1.7**	**1.8**	**2.0**	**2.2**
Residential	0.1	0.1	0.1	0.2	0.2	0.2
Commercial	0.4	0.4	0.4	0.4	0.5	0.5
Industrial	0.8	0.8	0.9	1.0	1.1	1.2
Transportation	0.0	0.0	0.0	0.0	0.0	0.0
Non-Energy	0.1	0.0	0.1	0.1	0.1	0.1
Own Uses and Losses	0.1	0.2	0.2	0.2	0.2	0.2
Electricity Generation	0.0	0.0	0.0	0.0	0.0	0.0
NGLs						
Total	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Residential	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0
Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Transportation	0.0	0.0	0.0	0.0	0.0	0.0
Non-Energy	0.1	0.1	0.1	0.1	0.1	0.1
Own Uses and Losses	0.0	0.0	0.0	0.0	0.0	0.0
COAL						
Total	**4.0**	**3.2**	**4.0**	**4.5**	**5.1**	**5.6**
CANADIAN BITUMINOUS						
Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Electricity Generation	0.8	0.9	0.9	1.0	1.2	1.3
U.S. BITUMINOUS						
Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Electricity Generation	2.6	1.9	2.5	2.9	3.2	3.6
LIGNITE						
Electricity Generation	0.6	0.4	0.5	0.6	0.7	0.8
WOOD/WASTE						
Total	**1.0**	**1.0**	**1.2**	**1.2**	**1.2**	**1.3**
Residential	0.2	0.2	0.2	0.3	0.3	0.3
Industrial	0.8	0.7	0.9	0.9	0.9	1.0
Electricity Generation	0.0	0.0	0.0	0.0	0.0	0.0
FOSSIL FUEL PRODUCTION						
Natural Gas Production	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Transportation	0.0	0.0	0.0	0.0	0.0	0.0
Oil Production	0.0	0.0	0.0	0.0	0.0	0.0
INDUSTRIAL PROCESSES						
Total	**21.2**	**16.9**	**17.4**	**6.8**	**7.9**	**8.9**
Cement Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0
Lime Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0
Kraft Pulp and Paper	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia Production	8.7	4.4	4.8	5.8	6.8	7.7
Nitric Acid Production	0.9	0.9	0.9	1.0	1.1	1.1
Adipic Acid Production	11.7	11.7	11.7	0.0	0.0	0.0
PRODUCT USAGE						
Raw CO2	0.0	0.0	0.0	0.0	0.0	0.0
N2O Anaesthetic	0.6	0.6	0.6	0.7	0.7	0.7
N2O Propellant	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 6.2
PRESENT AND FUTURE NITROUS OXIDE EMISSIONS (kilotonnes)

	YEAR					
SOURCES	1988	1990	1995	2000	2005	2010
INCINERATION						
Municipal Waste	0.1	0.1	0.1	0.1	0.1	0.1
Sewage Sludge	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Waste	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/Institutional Waste	0.0	0.0	0.0	0.0	0.0	0.0
Wigwam Burners	0.1	0.1	0.1	0.1	0.1	0.1
LANDFILLS AND SEWAGE TREATMENT						
Landfills	0.0	0.0	0.0	0.0	0.0	0.0
Sewage Treatment Plants	0.0	0.0	0.0	0.0	0.0	0.0
FIRES AND WOOD DECAY						
Structural Fires	0.0	0.0	0.0	0.0	0.0	0.0
Prescribed Fires	0.0	0.0	0.0	0.0	0.0	0.0
Forest Fires	1.4	1.4	1.4	1.4	1.4	1.4
Wood Product Decay	0.0	0.0	0.0	0.0	0.0	0.0
AGRICULTURE						
LIVESTOCK						
Cattle	0.0	0.0	0.0	0.0	0.0	0.0
Sheep	0.0	0.0	0.0	0.0	0.0	0.0
Swine	0.0	0.0	0.0	0.0	0.0	0.0
Turkeys	0.0	0.0	0.0	0.0	0.0	0.0
Horses	0.0	0.0	0.0	0.0	0.0	0.0
Goats	0.0	0.0	0.0	0.0	0.0	0.0
Chickens	0.0	0.0	0.0	0.0	0.0	0.0
MANURE						
Cattle	0.0	0.0	0.0	0.0	0.0	0.0
Sheep	0.0	0.0	0.0	0.0	0.0	0.0
Swine	0.0	0.0	0.0	0.0	0.0	0.0
Turkeys	0.0	0.0	0.0	0.0	0.0	0.0
Horses	0.0	0.0	0.0	0.0	0.0	0.0
Goats	0.0	0.0	0.0	0.0	0.0	0.0
Chickens	0.0	0.0	0.0	0.0	0.0	0.0
Fertilizer Use	1.2	1.2	1.2	1.2	1.2	1.3
LAND AND WATER SURFACES						
Soils	222.8	222.8	222.8	222.8	222.8	222.8
Wetlands	0.0	0.0	0.0	0.0	0.0	0.0
Lakes and Reservoirs	0.0	0.0	0.0	0.0	0.0	0.0
Lightning (over Forests)	0.5	0.5	0.5	0.5	0.5	0.5
Forest Harvesting	0.0	0.0	0.0	0.0	0.0	0.0
WILDLIFE						
Moose	0.0	0.0	0.0	0.0	0.0	0.0
Deer	0.0	0.0	0.0	0.0	0.0	0.0
Caribou	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOURCES	260.9	255.4	257.5	248.2	250.6	252.9

TABLE 6.2
PRESENT AND FUTURE NITROUS OXIDE EMISSIONS (kilotonnes)

	YEAR					
SOURCES	**1988**	**1990**	**1995**	**2000**	**2005**	**2010**
SINKS						
Forests	0.0	0.0	0.0	0.0	0.0	0.0
Lakes	0.0	0.0	0.0	0.0	0.0	0.0
Rivers	0.0	0.0	0.0	0.0	0.0	0.0
Wetlands (peat)	0.0	0.0	0.0	0.0	0.0	0.0
Soil	0.0	0.0	0.0	0.0	0.0	0.0
Transport to Stratosphere	16.8	16.5	16.6	16.0	16.2	16.3
Reaction with OH	0.0	0.0	0.0	0.0	0.0	0.0
Cultivated Land	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SINKS	**16.83**	**16.48**	**16.61**	**16.01**	**16.16**	**16.31**
NET EMISSIONS	**244.1**	**239.0**	**240.9**	**232.2**	**234.4**	**236.6**

Note: Bolded totals that do not match the actual totals are a result of round-off error

TABLE 6.3
PRESENT AND FUTURE METHANE EMISSIONS (kilotonnes)

	YEAR					
SOURCES	**1988**	**1990**	**1995**	**2000**	**2005**	**2010**
OIL PRODUCTS						
RESIDENTIAL						
Total	**0.26**	**0.23**	**0.20**	**0.19**	**0.16**	**0.14**
LFO	0.25	0.22	0.19	0.19	0.16	0.14
HFO	0.00	0.00	0.00	0.00	0.00	0.00
Kerosene	0.01	0.00	0.00	0.00	0.00	0.00
COMMERCIAL						
Total	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
LFO	0.01	0.01	0.01	0.01	0.01	0.01
HFO	0.01	0.00	0.00	0.00	0.00	0.00
Kerosene	0.00	0.00	0.00	0.00	0.00	0.00
INDUSTRIAL						
Total	**0.19**	**0.17**	**0.19**	**0.20**	**0.23**	**0.26**
LFO Construction	0.00	0.00	0.00	0.00	0.00	0.00
LFO Mining	0.00	0.00	0.00	0.00	0.00	0.00
LFO Other	0.00	0.00	0.00	0.00	0.00	0.00
HFO Agriculture	0.00	0.00	0.00	0.00	0.00	0.00
HFO Construction	0.00	0.00	0.00	0.00	0.00	0.00
HFO Chemicals	0.03	0.01	0.02	0.02	0.03	0.03
HFO Iron + Steel	0.03	0.03	0.03	0.03	0.04	0.04
HFO Mining	0.01	0.01	0.01	0.01	0.01	0.01
HFO Cement	0.00	0.00	0.00	0.00	0.00	0.00
HFO Pulp + Paper	0.01	0.01	0.01	0.01	0.01	0.01
HFO Other	0.02	0.03	0.02	0.03	0.03	0.03
Kerosene	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Agriculture	0.02	0.02	0.02	0.02	0.03	0.03
Diesel Construction	0.02	0.02	0.02	0.02	0.03	0.03
Diesel Chemicals	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Iron + Steel	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Mining	0.01	0.01	0.01	0.01	0.01	0.01
Diesel Pulp + Paper	0.00	0.00	0.00	0.00	0.01	0.01
Diesel Other	0.01	0.00	0.01	0.01	0.01	0.01
Gasoline Agriculture	0.02	0.02	0.02	0.02	0.02	0.03
Gasoline Other	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum Coke Mining	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum Coke Cement	0.00	0.00	0.01	0.01	0.01	0.01
Petroleum Coke Other	0.00	0.00	0.00	0.00	0.00	0.00
TRANSPORTATION						
Total	**1.35**	**1.31**	**1.43**	**1.51**	**1.62**	**1.74**
Motor Gasoline	0.91	0.89	0.97	1.02	1.10	1.18
Diesel	0.30	0.28	0.30	0.32	0.35	0.37
Aviation Turbo	0.13	0.11	0.13	0.13	0.14	0.15
Aviation Gas	0.00	0.00	0.00	0.00	0.00	0.00
Heavy Fuel Oil	0.02	0.03	0.03	0.03	0.03	0.04
OWN USES AND LOSSES	0.18	0.17	0.18	0.18	0.19	0.20
ELECTRICITY GENERATION	0.01	0.03	0.03	0.04	0.04	0.05

TABLE 6.3
PRESENT AND FUTURE METHANE EMISSIONS (kilotonnes)

	YEAR					
SOURCES	1988	1990	1995	2000	2005	2010
NATURAL GAS						
Total	**0.99**	**0.96**	**1.08**	**1.18**	**1.29**	**1.41**
Residential	0.28	0.28	0.31	0.34	0.37	0.40
Commercial	0.18	0.18	0.20	0.22	0.24	0.26
Industrial	0.41	0.40	0.44	0.48	0.53	0.58
Transportation	0.00	0.00	0.00	0.00	0.00	0.00
Non-Energy	0.04	0.02	0.04	0.04	0.04	0.05
Own Uses and Losses	0.07	0.08	0.08	0.09	0.10	0.11
Electricity Generation	0.01	0.01	0.01	0.01	0.01	0.01
NGLs						
Total	**0.10**	**0.08**	**0.09**	**0.09**	**0.10**	**0.10**
Residential	0.00	0.00	0.00	0.00	0.00	0.01
Commercial	0.01	0.01	0.01	0.01	0.01	0.01
Industrial	0.02	0.01	0.02	0.02	0.02	0.02
Transportation	0.02	0.02	0.02	0.02	0.02	0.02
Non-Energy	0.05	0.04	0.04	0.04	0.05	0.05
Own Uses and Losses	0.00	0.00	0.00	0.00	0.00	0.00
COAL						
Total	**0.35**	**0.29**	**0.35**	**0.40**	**0.45**	**0.50**
CANADIAN BITUMINOUS	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Generation	0.07	0.08	0.09	0.10	0.11	0.12
U.S. BITUMINOUS	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Generation	0.25	0.18	0.24	0.27	0.30	0.34
LIGNITE	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Generation	0.03	0.02	0.03	0.03	0.04	0.04
WOOD/WASTE						
Total	**2.02**	**1.90**	**2.25**	**2.32**	**2.39**	**2.46**
Residential	0.93	0.93	1.05	1.09	1.12	1.15
Industrial	1.08	0.92	1.16	1.19	1.23	1.27
Electricity Generation	0.01	0.05	0.04	0.04	0.04	0.04
FOSSIL FUEL PRODUCTION						
Natural Gas Production	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas Transportation	0.20	0.20	0.22	0.24	0.26	0.29
Oil Production	0.47	0.47	0.47	0.47	0.47	0.47
INDUSTRIAL PROCESSES						
Total	**0**	**0**	**0**	**0**	**0**	**0**
Cement Manufacturing	0.00	0.00	0.00	0.00	0.00	0.00
Lime Manufacturing	0.00	0.00	0.00	0.00	0.00	0.00
Kraft Pulp and Paper	0.00	0.00	0.00	0.00	0.00	0.00
Ammonia Production	0.00	0.00	0.00	0.00	0.00	0.00
Nitric Acid Production	0.00	0.00	0.00	0.00	0.00	0.00
Adipic Acid Production	0.00	0.00	0.00	0.00	0.00	0.00
PRODUCT USAGE						
Raw CO2	0.00	0.00	0.00	0.00	0.00	0.00
N2O Anaesthetic	0.00	0.00	0.00	0.00	0.00	0.00
N2O Propellant	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 6.3
PRESENT AND FUTURE METHANE EMISSIONS (kilotonnes)

SOURCES	YEAR 1988	1990	1995	2000	2005	2010
INCINERATION						
Municipal Waste	5.2	5.2	5.2	5.2	5.2	5.2
Sewage Sludge	1.2	1.2	1.3	1.4	1.5	1.5
Industrial Waste	0.7	0.7	0.7	0.7	0.7	0.7
Commercial/Institutional Waste	0.1	0.1	0.1	0.1	0.1	0.1
Wigwam Burners	0.1	0.1	0.1	0.1	0.1	0.1
LANDFILLS AND SEWAGE TREATMENT						
Landfills	569.8	601.1	628.5	651.0	671.2	696.7
Sewage Treatment Plants	129.6	134.0	145.8	155.6	163.5	171.8
FIRES AND WOOD DECAY						
Structural Fires	0.3	0.3	0.3	0.3	0.3	0.3
Prescribed Fires	0.2	0.2	0.2	0.2	0.2	0.2
Forest Fires	17.2	17.2	17.2	17.2	17.2	17.2
Wood Product Decay	0.0	0.0	0.0	0.0	0.0	0.0
AGRICULTURE						
LIVESTOCK						
Cattle	125.7	123.8	123.8	126.9	130.1	133.4
Sheep	1.6	1.7	1.7	1.8	1.8	1.9
Swine	5.1	4.7	4.7	4.8	5.0	5.1
Turkeys	6.2	6.2	6.2	6.4	6.5	6.7
Horses	5.4	5.4	5.4	5.5	5.7	5.8
Goats	0.3	0.3	0.3	0.3	0.3	0.3
Chickens	96.0	96.0	96.0	98.4	100.9	103.5
MANURE						
Cattle	54.6	53.8	53.8	55.1	56.5	58.0
Sheep	0.3	0.4	0.4	0.4	0.4	0.4
Swine	25.3	23.6	23.6	24.2	24.8	25.5
Turkeys	1.2	1.2	1.2	1.3	1.3	1.3
Horses	10.8	10.8	10.8	11.0	11.3	11.6
Goats	0.1	0.1	0.1	0.1	0.1	0.1
Chickens	6.4	6.4	6.4	6.6	6.7	6.9
Fertilizer Use	0.0	0.0	0.0	0.0	0.0	0.0
LAND AND WATER SURFACES	0.0	0.0	0.0	0.0	0.0	0.0
Soils	0.0	0.0	0.0	0.0	0.0	0.0
Wetlands	555.6	555.6	555.6	555.6	555.6	555.6
Lakes and Reservoirs	42.6	42.6	42.6	42.6	42.6	42.6
Lightning (over Forests)	0.0	0.0	0.0	0.0	0.0	0.0
Forest Harvesting	0.0	0.0	0.0	0.0	0.0	0.0
WILDLIFE						
Moose	3.7	3.7	3.7	3.7	3.7	3.7
Deer	5.6	5.6	5.6	5.6	5.6	5.6
Caribou	0.5	0.5	0.5	0.5	0.5	0.5
TOTAL SOURCES	1677.3	1708.2	1748.2	1789.3	1826.5	1869.8

TABLE 6.3
PRESENT AND FUTURE METHANE EMISSIONS (kilotonnes)

SOURCES	YEAR					
	1988	1990	1995	2000	2005	2010
SINKS						
Forests	560.0	553.7	538.4	523.5	509.0	494.9
Lakes	0.0	0.0	0.0	0.0	0.0	0.0
Rivers	0.0	0.0	0.0	0.0	0.0	0.0
Wetlands (peat)	0.0	0.0	0.0	0.0	0.0	0.0
Soil	0.0	0.0	0.0	0.0	0.0	0.0
Transport to Stratosphere	0.0	0.0	0.0	0.0	0.0	0.0
Reaction with OH	564.3	564.3	564.3	564.3	564.3	564.3
Cultivated Land	56.5	56.5	56.5	56.5	56.5	56.5
TOTAL SINKS	**1180.8**	**1174.5**	**1159.2**	**1144.3**	**1129.8**	**1115.7**
NET EMISSIONS	**496.5**	**533.7**	**588.9**	**645.0**	**696.7**	**754.0**

Note: Bolded totals that do no match the actual totals are a result of round-off error

TABLE 6.4
PRESENT AND FUTURE CFC EMISSIONS (tonnes)

			YEAR			
SOURCE	1988	1990	1995	2000	2005	2010
Fugitive Emissions						
CFC-11	0	0	0	0	0	0
CFC-12	670	508	178	3	3	3
CFC-113	135	100	35	1	1	1
Refrigeration						
Total	**3,644**	**2,945**	**2,384**	**765**	**521**	**360**
CFC-11	400	0	0	0	0	0
CFC-12	1,944	1,645	1,084	715	471	310
CFC-113	1,300	1,300	1,300	50	50	50
Open Cell Foam						
Total	**1240.05**	**0**	**0**	**0**	**0**	**0**
CFC-11	166	0	0	0	0	0
CFC-12	1,074	0	0	0	0	0
Closed Cell Foam						
Total	**3,254**	**575**	**575**	**0**	**0**	**0**
CFC-11	2,166	0	0	0	0	0
CFC-12	506	0	0	0	0	0
CFC-113	582	575	575	0	0	0
Solvent						
CFC-113	1,113	6,325	1,325	0	0	0
Aerosol						
CFC-12	810	0	0	0	0	0
Miscellaneous						
CFC-113	304	2,863	0	0	0	0
TOTAL ONTARIO EMISSIONS						
CFC-11	2,731	0	0	0	0	0
CFC-12	5,004	8,830	3,402	1,426	958	650
CFC-113	3,434	2,323	737	14	14	14
GRAND TOTAL	**11,169**	**11,153**	**4,139**	**1,440**	**972**	**664**
SINKS	**720**	**719**	**267**	**93**	**63**	**43**
NET EMISSIONS	**10,449**	**10,434**	**3,872**	**1,347**	**909**	**621**

in refrigerators. On a CO_2 equivalent basis, emissions of CFCs fall from 58,107 kilotonnes in 1988 to 4,790 kilotonnes in 2010.

6.5 GREENHOUSE GASES

Forecast net emissions of the total CO_2, CH_4, N_2O and CFCs in Ontario, expressed in terms of CO_2 equivalence, rises from 174,270 kilotonnes in 1988 to 212,344 kilotonnes in 2010.

7.0 RELATIVE CONTRIBUTION TO WARMING

7.1 GLOBAL WARMING

The Earth receives incoming energy from the Sun in the form of short wave radiation. To balance the energy flow, the Earth emits infrared radiation into space. Several gases found in the atmosphere are transparent to solar radiation but absorb infrared radiation, thereby trapping heat and warming the lower atmosphere and the Earth's surface. This partial trapping of outgoing infrared radiation and consequent warming of the surface and lower atmosphere is called the greenhouse effect.

Although the concentrations of these "greenhouse" gases in the atmosphere are very low, they are increasing as a result of human activity. The rising concentrations are projected to lead to further warming of the surface and lower atmosphere. The projected temperature rise due to increased atmospheric concentrations of greenhouse gases is called global warming.

7.2 GREENHOUSE GASES

Greenhouse gases are gases that absorb radiation in some part of the infrared spectrum. They include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halocarbons (CFCs, HCFCs and HFCs), and tropospheric ozone (O_3).[1] Tropospheric ozone is formed in the atmosphere through chemical reactions involving nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs) in the presence of sunlight and appropriate temperatures. Since these three gases lead to the formation of greenhouse gases in the atmosphere they are called greenhouse gas precursors. Carbon monoxide (CO) also forms carbon dioxide and acts to increase the atmospheric lifetime, and hence concentrations, of CH_4 and CFCs.

The greenhouse gases and their precursors have different residence times in the atmosphere and have different capacities to absorb infrared radiation and hence to trap heat.[2] Efforts to address global warming focus on reducing future atmospheric concentrations of the greenhouse gases. Since the gases have different heat trapping capacities and atmospheric residence times, the obvious question becomes what is the most effective way to control global warming? The global warming potential (GWP) index is intended to provide a basis for comparing the global warming impacts of different greenhouse gases so that this question can be answered.

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[1] Water vapour (H_2O) also absorbs infrared radiation directly and significantly, but the concentration of water vapour in the atmosphere is not considered to be significantly affected by direct human activity. An increase in atmospheric water vapour occurs as the climate warms. This is included as part of the calculated climate model response to anthropogenic greenhouse gas emissions.

7.3 GLOBAL WARMING POTENTIAL (GWP) INDEX

Conceptually the notion of the global warming potential (GWP) index is simple; it is to compare the global warming effect of a given greenhouse gas to that of a similar quantity of carbon dioxide. Carbon dioxide is selected as the base against which other gases are compared because it is the least potent and by far the most abundant of the greenhouse gases.

The global warming potential index measures the warming effect of a release of one kilogram of a greenhouse gas into the atmosphere relative to that of the release of one kilogram of carbon dioxide, integrated over a given time horizon. Mathematically the global warming potential index for greenhouse gas *i* is calculated as follows:

$$gwp_1 = \frac{\int_o^T f_i * C_i(t)\ dt}{\int_o^T f_i * C_c(t)\ dt}$$

where f_i is the heat trapping ability of a one kilogram increase of gas *i* and $C_i(t)$ is the fraction of the kilogram of gas *i* released, remaining in the atmosphere at time t. The corresponding quantities for carbon dioxide are f_c and $C_c(t)$. The time horizon over which the global warming impacts are compared, the integration period, is T.

The global warming potential index is modelled on the approach used to calculate the ozone depleting potential (ODP) of different ozone depleting gases, such as CFCs. The integration period used to calculate the ozone depletion index is infinity ($T=\infty$). To use an infinite integration period, both gases must have a finite atmospheric lifetime. All of the greenhouse gases, except CO_2, have a finite atmospheric lifetime.

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[2] The capacity of a gas to absorb infrared radiation is its instantaneous radiative forcing.

7.4 APPROACHES TO DEALING WITH THE INFINITE LIFETIME OF CO_2

Greenhouse gases, other than carbon dioxide, are destroyed in the atmosphere through chemical reactions. Thus, the concentration of an initial release gradually declines. Although some fraction continues to trap infrared radiation thousands of years later, eventually all of the gas from the initial release is removed from the atmosphere. The rate at which the concentration declines varies significantly for different gases.

Carbon dioxide is not destroyed in the atmosphere, it is removed from the atmosphere primarily through photosynthetic processes or direct absorption into water. Approximately one-quarter of the CO_2 in the atmosphere is removed annually by these processes. However almost all of the CO_2 removed finds its way back into the atmosphere through biological respiration and decay or ocean out-gassing.

Ultimately, about 85 percent of the initial release of CO_2 is removed by mixing into the ocean, but only over a period of several hundred to a thousand years. Another 10 percent will be removed by dissolution of marine carbonate sediments over a period of several thousand years. The remaining 5 percent or so is removed over a period of 100,000 years through silicate rock weathering. Hence, on human time scales carbon dioxide does not have a finite atmospheric lifetime like other greenhouse gases.

The initial approach to calculating global warming potential index values for greenhouse gases by Lashof and Ajuha (1990) dealt with this problem by assigning carbon dioxide an arbitrary atmospheric "lifetime" of 50 to 200 years. The lifetime chosen for CO_2 affects the GWPs of all greenhouse gases, but does not change the relative GWPs of the other gases.

The Intergovernmental Panel on Climate Change (IPCC) adopted a different approach to dealing with the infinite life of the carbon dioxide. It calculated the global warming impacts of carbon dioxide and other greenhouse gases over specified periods and ignored the residual warming effects that might still occur beyond the end of the integration period. The IPCC used periods of 20, 100, and 500 years for its calculations. The global warming potentials estimated for various greenhouse gases by the IPCC are shown in Table 7.1. The values shown in the table reflect both the direct and indirect warming effects of each gas.

By definition, the GWP for carbon dioxide is 1 for all time horizons. And since carbon dioxide has the lowest heat trapping capacity of the primary greenhouse gases all of these gases have GWPs greater than 1. Indeed most are hundreds or thousands of times more potent than carbon dioxide. Note that the GWPs of gases with relatively short atmospheric residence times (e.g. methane and HCFC-22) decline much more than those for gases with relatively long (e.g. nitrous oxide, CFC-12) lifetimes as the time horizon grows.

The GWP offers a simple yet reasonable characterization of the relative radiative effects of well-mixed greenhouse gases. It does, however, have limitations when applied to ozone (O_3) and its precursors because these gases are not well mixed and so demonstrate marked spatial and temporal variations. The GWP values are global and annual averages, and do not reflect the spatial and temporal variations of the non well-mixed gases.

The IPCC believes that the 100 year integration period provides a balanced representation of the various time horizons for climate response. It is a time scale that includes due consideration of the ocean thermal inertia and its impacts on global mean temperature and the time scale over which a significant fraction of CO_2 is removed from the atmosphere. The 1990 IPCC GWP values for the 100 year integration period are used to determine the equivalence of different greenhouse gases. Table 7.2 lists the 1988 CO_2 equivalents for CO_2, N_2O, CH_4 and CFCs. The IPCC 100-year GWP index values were used as they are the currently accepted international convention.

Table 7.1

GLOBAL WARMING POTENTIALS AS COMPUTED BY THE IPCC FOR TIME HORIZONS OF 20, 100 AND 500 YEARS

		Time Horizon		
Gas	Lifespan	20 years	100 years	500 years
CO_2	---	1	1	1
CH_4	10	63	21	9
N_2O	150	270	290	190
CFC-11	60	4500	3500	1500
CFC-12	130	7100	7300	4500
HCFC-22	15	4100	1500	510
NO_x	---	150	40	14
CO	1	5	1	1

Sources: J.T. Houghton, G.J. Jenkins and J.J. Ephraums, Climate Change: The IPCC Scientific Assessment, Cambridge University Press, 1990, Table 3, p.xx; and L.D.D. Harvey, "A Guide to Global Warming Potentials (GWP's)", mimeo, November, 1991. Table 3, page 18.

TABLE 7.2
1988 CO2 EQUIVALENTS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

	POLLUTANT				
SOURCES	CO2	CH4	N20	CFCs	TOTAL
OIL PRODUCTS					
RESIDENTIAL					
Total	**4,475**	**5**	**63**	**0**	**4,543**
LFO	4,197	5	58		4,260
HFO	15	0	0		15
Kerosene	264	0	4		268
COMMERCIAL					
Total	**1,422**	**0**	**41**	**0**	**1,463**
LFO	1,082	0	15		1,097
HFO	252	0	25		276
Kerosene	88	0	1		89
INDUSTRIAL					
Total	**6,830**	**4**	**164**	**0**	**6,998**
LFO Construction	95	0	1		96
LFO Mining	29	0	0		30
LFO Other	22	0	0		22
HFO Agriculture	7	0	0		8
HFO Construction	7	0	0		8
HFO Chemicals	999	1	13		1,013
HFO Iron + Steel	1,080	1	14		1,095
HFO Mining	192	0	3		195
HFO Cement	37	0	0		38
HFO Pulp + Paper	363	0	5		368
HFO Other	533	0	7		540
Kerosene	14	0	0		14
Diesel Agriculture	679	0	29		708
Diesel Construction	643	0	28		671
Diesel Chemicals	7	0	0		7
Diesel Iron + Steel	49	0	2		52
Diesel Mining	254	0	11		266
Diesel Pulp + Paper	141	0	6		148
Diesel Other	353	0	15		369
Gasoline Agriculture	625	0	19		645
Gasoline Other	122	0	4		126
Pet. Coke Mining	132	0	1		133
Pet. Coke Cement	349	0	3		352
Pet. Coke Other	94	0	1		95

TABLE 7.2
1988 CO2 EQUIVALENTS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

	POLLUTANT				
SOURCES	**CO2**	**CH4**	**N20**	**CFCs**	**TOTAL**
TRANSPORTATION					
Total	**44,349**	**28**	**1,435**	**0**	**45,813**
Motor Gasoline	29,313	19	890		30,222
Diesel	9,939	6	427		10,372
Aviation Turbo	4,236	3	106		4,345
Aviation Gas	76	0	2		78
Heavy Fuel Oil	784	0	10		795
OWN USES AND LOSSES	6,017	4	79		6,100
ELECTRICITY GENERATION	476	0	6		483
NATURAL GAS					
Total	**41,840**	**21**	**446**	**0**	**42,308**
Residential	12,594	6	37		12,636
Commercial	7,566	4	106		7,676
Industrial	16,807	9	235		17,051
Transportation	25	0	0		25
Non-Energy	1,495	1	21		1,517
Own Uses and Losses	2,926	1	41		2,969
Electricity Generation	427	0	6		433
NGLs					
Total	**4,147**	**2**	**58**	**0**	**4,207**
Residential	180	0	3		182
Commercial	245	0	3		249
Industrial	874	0	12		886
Transportation	730	0	10		741
Non-Energy	2,118	1	30		2,149
Own Uses and Losses	0	0	0		
COAL					
Total	**48,809**	**7**	**1,150**	**0**	**49,966**
CANADIAN BITUMINOUS					
Industrial	3,073	0	0		3,073
Electricity Generation	6,521	1	219		6,742
U.S. BITUMINOUS					
Industrial	14,098	0	0		14,098
Electricity Generation	21,887	5	763		22,656
LIGNITE					
Electricity Generation	3,230	1	167		3,398
WOOD/WASTE					
Total	**9,383**	**42**	**303**	**0**	**9,729**
Residential	1,549	19	63		1,630
Industrial	7,753	23	238		8,013
Electricity Generation	81	0	3		85

TABLE 7.2
1988 CO2 EQUIVALENTS FOR THE PROVINCE OF ONTARIO (In kilotonnes)

POLLUTANT

SOURCES	CO2	CH4	N20	CFCs	TOTAL
FOSSIL FUEL PRODUCTION					
Natural Gas Production	36	0	0		36
Natural Gas Transportation	2,049	4	7		2,060
Oil Production	61	10	0		71
INDUSTRIAL PROCESSES					
Total	**6,175**	**0**	**6,157**	0	**12,332**
Cement Manufacturing	2,720	0	0		2,720
Lime Manufacturing	1,418	0	0		1,418
Kraft Pulp and Paper	441	0	0		441
Ammonia Production	1,596	0	2,522		4,118
Nitric Acid Production	0	0	257		257
Adipic Acid Production	0	0	3,379		3,379
PRODUCT USAGE					
Raw CO2	1	0	0		1
N2O Anaesthetic	0	0	164		164
N2O Propellant	0	0	8		8
CFC EMISSIONS					
Total	**0**	**0**	0	**58,107**	**58,107**
CFC-11	0	0	0	9560	9,560
CFC-12	0	0	0	36528	36,528
CFC-113	0	0	0	12019	12,019
INCINERATION					
Municipal Waste	721	109	37		867
Sewage Sludge	153	24	11		188
Industrial Waste	118	14	6		139
Commercial/Institutional Waste	12	2	1		15
Wigwam Burners	850	2	27		879
LANDFILLS AND SEWAGE TREATMENT					
Landfills	1,792	11,966	0		13,758
Sewage Treatment Plants	0	2,722	0		2,722
FIRES AND WOOD DECAY					
Structural Fires	215	6	7		227
Prescribed Fires	133	4	4		141
Forest Fires	12,617	360	398		13,375
Wood Product Decay	28,208	0	0		28,208

TABLE 7.2
1988 CO2 EQUIVALENTS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

POLLUTANT

SOURCES	CO2	CH4	N20	CFCs	TOTAL
AGRICULTURE					
LIVESTOCK					
Cattle	0	2,639	0		2,639
Sheep	0	34	0		34
Swine	0	106	0		106
Turkeys	0	130	0		130
Horses	0	113	0		113
Goats	0	5	0		5
Chickens	0	2,016	0		2,016
MANURE					
Cattle	0	1,147	0		1,147
Sheep	0	7	0		7
Swine	0	531	0		531
Turkeys	0	26	0		26
Horses	0	226	0		226
Goats	0	2	0		2
Chickens	0	134	0		134
Fertilizer Use	0	0	334		334
LAND AND WATER SURFACES					
Soils	0	0	64,611		64,611
Wetlands	0	11,667	0		11,667
Lakes and Reservoirs	0	894	0		894
Lightning (over Forests)	0	0	138		138
Forest Harvesting	3,484	0	0		3,484
WILDLIFE					
Moose	0	78	0		78
Deer	0	118	0		118
Caribou	0	11	0		11
TOTAL EMISSIONS	**224,372**	**35,224**	**75,656**	**58,107**	**393,359**
SINKS					
Forests	139,200	11,760	0		150,960
Lakes	3,885	0	0		3,885
Rivers	8,083	0	0		8,083
Wetlands (peat)	25,397	0	0		25,397
Soil	5,614	0	0		5,614
Transport to Stratosphere	0	0	4,880	3,748	8,628
Reaction with OH	0	11,850	0		11,850
Cultivated Land	0	1,187	0		1,187
TOTAL SINKS	**182,180**	**24,797**	**4,880**	**3,748**	**215,604**
NET TOTAL EMISSIONS	**42,192**	**10,427**	**70,776**	**54,359**	**177,755**

Note: This table is based on applying the GWPs from Table 7.1, using the 100 year time horizon

7.5 UNCERTAINTIES IN GWP CALCULATIONS

The uncertainties in the GWP calculations are due to uncertainties concerning three factors:

- atmospheric fraction of a unit release of the gas remaining at each point in time, $C_i(t)$, especially for carbon dioxide;
- the direct radiative forcing of one additional kilogram of the gas, f_i, in the atmosphere; and
- its indirect radiative effects.

A summary of the uncertainties relating to the various greenhouse gases is provided in the appendix. The GWP values for the 100 year time horizon and the associated uncertainties are summarized in Table 7.3.

The radiative forcing of a given gas depends on its background concentration as well as the concentration of other greenhouse gases in the atmosphere. Hence, the GWP of a given gas depends, to some degree, on the concentrations of all greenhouse gases and precursors in the atmosphere. The GWPs are calculated using current concentrations, which are likely to change as a result of past and future policy measures (e.g., the commitment to phase out CFCs). This adds to the uncertainty for the GWP values for longer integration periods and it means that future GWPs will differ from current estimates.

The IPCC has updated the 1990 GWP values to reflect revisions to the lifetimes of radiatively active species, the impacts of observed stratospheric ozone losses, a more thorough assessment of the indirect effects of gases that alter atmospheric concentrations of greenhouse gases, and to correct calculation and reporting errors. The 1992 direct GWP values adopted by the IPCC are shown in Table 7.4. The new direct GWPs are generally within 20 percent of the 1990 values for direct impacts. Further changes in GWPs can be expected as additional research results become available.

Table 7.3

SUMMARY OF GWP ESTIMATES (100 YEAR INTEGRATION PERIOD)

Gas	IPCC 1990 Values	Confidence* Level	Comments
CO_2			
Direct	1	n.a.	Defined as 1
Indirect	?	L	Warming due to O_3 increase
Net	1	VH	
Methane			
Direct	6	H	Within +/- 25%
Indirect			
i) via CO_2	3	H	Assumes CO_2 attributes
ii) via H_2O	4	L	Stratosphere only
iii) via O_3	8	VL	Spatially, temporally & chemically variable
Net	21	M	
N_2O	290	M	
Direct	?	L	Within factor of 2
Indirect	290	M	O_3 related cooling
Net			
CFCs	3500 to 7300	VH	
Direct	?	L-M	Well defined variables
Indirect	variable	L-M	Large & latitude-dependent
Net			Cooling, amount uncertain positive over equator, negative at poles
NO_x			
Indirect	40	VL	
i) low release	?	L	Spatially and temporally
ii) hi release			variable. 1990 values 5_x too
	?	VL	high
Net			
CO/VOCs			
Indirect	2/3	H	
i) via CO_2			CO_2 produced becomes well-mixed
ii) via O_3	1/8	VL	Spatially, temporally and
	Approx. 0.8	L	chemically variable
Net			

* Subjectively assessed. VH = very high; H = high; m - medium; L = low; VL = very low

Source: H. Hengeveld, "Global Warming Potential", mimeo, August 12, 1991.

Table 7.4

DIRECT GLOBAL WARMING POTENTIALS AS COMPUTED BY THE IPCC, 1992

Gas	Lifetime	20 years	100 years	500 years
CO_2		1	1	1
CH_4	10.5	34	11	4
N_2O	132	250	270	170
CFC-11	55	4400	3400	1400
CFC-12	116	7000	7100	4100
HCFC-22	15.8	4100	1600	540
CFC-113	110	4400	4500	2500
CFC-114	220	5900	7000	5800
CFC-115	550	5300	7000	8500
HCFC-123	1.75	330	93	30
HCFC-124	7.1	1500	460	150
HFC-125	40.5	5100	3400	1200
HFC-134a	15.6	3100	1200	400
HCFC-141b	11.4	1800	610	210
HCFC-142b	22.6	3900	1800	630
HFC-143a	64.2	4600	3800	1600
HFC-152a	1.8	520	150	49
$CC1_4$	47	1800	1300	480

Source: IPCC, Greenhouse Gases: Sources and Sinks, Draft, December, 1991, Table 1.2.1

7.6 USE OF GWPS

The Global Warming Potential index is a helpful, but imperfect tool. It provides a rough estimate of the potential climate response to greenhouse gas emissions.

To use the GWPs calculated by the IPCC it is necessary to select a time horizon. A shorter time horizon, such as 20 years, emphasizes the more immediate effects of emissions on the **rate** of climate change without considering the deferred effects of gases remaining in the atmosphere at the end of the period. Longer integration periods emphasize the **magnitude** of climate change due to the emissions.

GWPs are often used to assess the net effect of measures that reduce the emissions of one greenhouse gas but increase emissions of another. For example, converting an electricity generating station from coal to natural gas would reduce CO_2 emissions and might increase methane emissions over the remaining lifetime of the station.

GWPs are calculated assuming an instantaneous emission of each gas. Continuous emissions of the two gases at the same rate to time T yields the same GWP index value. The 100-year index, for example, assumes an instantaneous release of one kilogram of the gas, but the same value is obtained if the gas and the carbon dioxide are both released continuously at the same rate for 100 years. The GWP of a measure that releases greenhouse gases continuously over a period that differs from the integration period must be calculated based on the pattern of emissions. The GWP's for selected integration periods of measures that release greenhouse gases over various lifetimes are shown in Table 7.5.

If the measure lifetime (e.g., 40 years) is shorter than the integration period (e.g., 500 years) the GWP's fall rapidly. This reflects the destruction of the gases after the emissions have ceased and is particularly pronounced for gases, such as methane, whose life is short relative to carbon. To assess the global warming impacts after 100 years of greenhouse gases emitted by a specific generating station with a 40-year life the appropriate values from Table 7.5 should be used. If the station is assumed to be replaced by one with identical emissions of greenhouse gases every

Table 7.5

GREENHOUSE WARMING POTENTIALS FOR CH_4, CO, AND HCFC-22 FOR DIFFERENT TIME HORIZONS AND INVESTMENT LIFETIMES

	Time Horizon (Years)									
	20		100				500			
	Measure Lifetime (Years)		Measure Lifetime (Years)				Measure Lifetime (Years)			
	10	20	10	20	40	100	10	20	40	500
CH_4	25.9	42.7	1.1	1.1	1.2	15.1	1.0	1.0	1.0	6.0
HCFC-22	5,746	7,600	57	81	181	3,019	0.0	0.0	0.0	1,076
CO	1.0	4.9	1.0	1.0	1.0	2.1	1.0	1.0	1.0	1.4

Source: L.D. Danny Harvey, "A Guide to Global Warming Potentials", November 19, 1991.

40 years, then the measure life and the integration period are the same and the GWP index values from Table 7.1 should be used.

7.7 ECONOMIC GWPS

The GWPs are based on the physical properties of the respective gases, their radiative forcing and atmospheric residence times. Some authors have proposed that other considerations be incorporated into the index as well.[3] For example, Reilly argues that the GWP should be an index of the economic effect of global warming due to emissions of greenhouse gases. This would require adjustments to the index because:

- marginal damages are likely to vary over time;
- gases have economic effects that should be counted as credits (e.g., direct fertilization of crops by CO_2) or debits (e.g., stratospheric ozone depletion by CFCs); and
- programs that limit emissions or enhance sinks are not accurately described as a one-time change in emissions but have unique time profiles.

Reilly's economic index discounts future costs and benefits and so does not require selection of an integration period. His preliminary estimates of economic GWPs are shown in Table 7.6. The index values are higher than those of the IPCC due to the economic credit for carbon dioxide fertilization of crops.

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[3] See R.S. Eckaus, "Comparing the Effects of Greenhouse Gas Emissions on Global Warming", MIT-CEPR 90-022WP, Center for Energy Policy Research, Massachusetts Institute of Technology, November, 1990; R.B.Stewart and J.B. Wiener, "A Comprehensive Approach to Climate Change", The American Enterprise, November/December, 1990, pp. 75-80; and J. Reilly, "Climate Change and the Trace Gas Issue", draft, mimeo, U.S. Department of Agriculture, Washington, D.C., November, 1990.

The index values are higher than those of the IPCC due to the economic credit for carbon dioxide fertilization of crops.

Table 7.6

COMPARISONS OF TRACE GAS INDICES

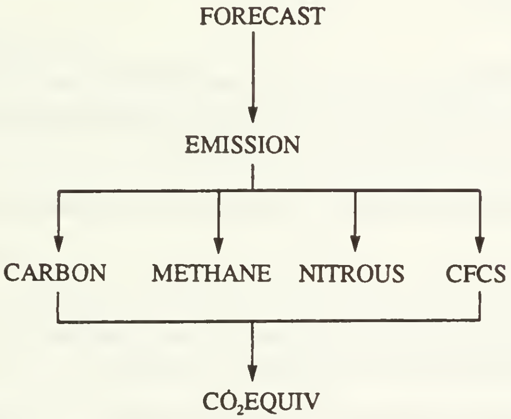
	Economic Index	Radiative Forcing	IPCC-GWP 20 year	IPCC-GWP 500 year
CO_2	1	1	1	1
CH_4	92	58	63	9
N_2O	260	206	270	190
CFC-11	6343	3970	4500	1500
CFC-12	9119	5750	7100	4500
CFC-113	5917	3710	4500	2100
HCFC-22	8950	5440	4100	510
CO	3.7	2.3	7	2

Source: J. Reilly, "Climate Change and the Trace Gas Issue", draft, mimeo, U.S. Department of Agriculture, Washington, D.C., November, 1990, Table 3, p. 16.

8.0 GREENHOUSE GAS INVENTORY AND FORECAST MODEL

The greenhouse gas emissions forecast model projects emissions and sequestration of greenhouse gases annually over the period 1988 to 2010. The model is structured as a series of linked Lotus 123 spreadsheets.

The spreadsheets are linked as follows:



Briefly, the calculations performed by each spreadsheet are:

FORECAST:	This spreadsheet contains the inputs to the forecast and calculates the projected base values. It also contains the emissions coefficients for CO_2, CH_4, and N_2O for each source and sink.
CARBON, METHANE, and NITROUS:	The projected base values and emissions coefficients are drawn from FORECAST. The base values for each year are multiplied by the appropriate emissions coefficient to get the projected emissions of the gas by each source and sink for the year. The emissions of each gas are converted to CO_2 equivalents using the IPCC 100-year global warming potential index values.

CFCS: This spreadsheet draws Canadian production of CFCs by type from FORECAST. It then calculates Ontario use of CFCs by type and Ontario emissions of CFCs by type. The Ontario emissions are expressed as CO_2 equivalents using the IPCC 100-year global warming potential index values.

CO_2EQUIV: This spreadsheet draws the CO_2 equivalent values by source and sink for each year from CARBON, METHANE, NITROUS and CFCS and sums them to get net total emissions of greenhouse gas emissions by year expressed as CO_2 equivalent.

The spreadsheets, with the exception of CFCs, have similar structures in that they all use the same set of sources and sinks and all cover the 23 years from 1988 through 2010.

The spreadsheets, except CFCS, cover rows 1 to 186 and have the following structure:

FORECAST: ABCDEF, where
A is a column (b) with the names of the sources and sinks
B is a column (d) with the units of the input variables
C is a matrix (f..ab) with the values of the inputs to the forecast by year
D is a column (ad) with the units of the base values
E is a matrix (af..bb) of the projected base values by year
F is a matrix (bd..bf) of the emissions coefficients for CO_2, CH_4 and N_2O respectively for each source and sink.

CARBON: ABEFGH, where
A is a column (b) with the names of the sources and sinks
B is a column (d) with the units of the input variables
E is a matrix (f..ab) of the projected base values by year
F is a matrix (ad..af) of the emissions coefficients for CO_2, CH_4, and N_2O respectively for each source and sink

G is a matrix (ah..bd) of forecast CO_2 emissions by source and sink for each year from 1988 through 2010 in kilotonnes

H is a matrix (bf..cb) of forecast CO_2 emissions by source and sink for each year from 1988 through 2010 in kilotonnes.

E and F are linked to FORECAST and so are updated automatically if the forecast changes. The values in H are calculated by multiplying the values in G by the global warming potential (GWP) index for CO_2. Since the GWP for CO_2 is 1 the values in G and H are identical.

METHANE: ABEFIJ, where

A is a column (b) with the names of the sources and sinks

B is a column (d) with the units of the input variables

E is a matrix (ad..af) of the projected base values by year

F is a matrix (ad..af) of the emissions coefficients for CO_2, CH_4, and N_2O respectively for each source and sink

I is a matrix (ah..bd) of forecast CH_4 emissions by source and sink for each year from 1988 through 2010 in tonnes

J is a matrix (bf..cb) of forecast CH_4 emissions by source and sink for each year from 1988 through 2010 expressed as CO_2 equivalent in kilotonnes.

E and F are linked to FORECAST and so are updated automatically if the forecast changes. The values in J are calculated by multiplying the values in I by the global warming potential (GWP) index for CH_4 (21) and dividing by 1,000.

NITROUS: ABEFKL, where

A is a column (b) with the names of the sources and sinks

B is a column (d) with the units of the input variables

E is a matrix (f..ab) of the projected base values by year

F is a matrix (ad..af) of the emissions coefficients for CO_2, CH_4, and N_2O respectively for each source and sink

K is a matrix (ah..bd) of forecast N_2O emissions by source and sink for each year from 1988 through 2010 in tonnes

L is a matrix (bf..cb) of forecast N_2O emissions by source and sink for each year from 1988 through 2010 expressed as CO_2 equivalent in kilotonnes.

E and F are linked to FORECAST and so are updated automatically if the forecast changes. The values in L are calculated by multiplying the values in K by the global warming potential (GWP) index for N_2O (290) and dividing by 1,000.

CFCs: ABM, where

A is a column (B) with the names of the sources and sinks

B is a column (d) with the units of the input variables

M is a matrix (f..ab) for the years 1988 through 2010. Canadian production of CFCs, Ontario use of CFCs, and Ontario emissions of CFCs are calculated on different rows as discussed below.

Canadian production of CFCs is drawn from matrix F of FORECAST so this spreadsheet is updated automatically if the forecast changes.

CO_2EQUIV: ABHJLN, where

A is a column (b) with the names of the sources and sinks

B is a column (d) with the units of the input variables

H is a matrix (f..ab) of forecast CO_2 emissions by source and sink for each year from 1988 through 2010 in kilotonnes

J is a matrix (ad..az) of forecast CH_4 emissions by source and sink for each year from 1988 through 2010 in kilotonnes of CO_2 equivalent

L is a matrix (bb..bx) of forecast N_2O emissions by source and sink for each year from 1988 through 2010 in kilotonnes of CO_2 equivalent.

N is a matrix (bz..cv) of forecast emissions of greenhouse gases by source and sink for each year from 1988 through 2010 in kilotonnes of CO_2 equivalent.

H, J, and L are linked to CARBON, METHANE, and NITROUS respectively so that this spreadsheet is automatically updated if the forecast changes. The CO_2 equivalents of the CFC emissions are entered into matrix H. They appear in rows 124 through 126. These rows are linked to rows 76 through 78 of CFCS so that they are updated automatically if the forecast changes. The values in N are calculated as the sum of the corresponding cells of H, J, and L and so represent total emissions of greenhouse gases expressed as CO_2 equivalents.

CFC EMISSIONS MODEL

To forecast the global warming effect of CFCs it is necessary to estimate emissions by type of CFC and by use. Different CFCs have significantly different global warming potentials so they must be distinguished. Some uses result in virtually immediate release of the CFCs while others delay the emissions for a decade or more, so use can have a significant impact on the timing of emissions.

Calculation of Ontario emissions of CFCs is performed in rows 41 through 62 of the spreadsheet CFCS. Total emissions of CFC-11, CFC-12, and other CFCs by year are shown in rows 64 through 67 of CFCS.

Global Warming Potential of CFC Emissions

The IPCC global warming potential index values for the 100 year integration period are applied to the Ontario emissions of CFCs to convert them to CO_2 equivalents. The GWP index values are 3,500 for CFC-11, 7,300 for CFC-12 and 3,500 for other CFCs. The CO_2 equivalents of the CFC emissions are calculated in rows 75 through 78 of CFCS. The values from these rows are linked to rows 124 to 126 of CO_2EQUIV.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

- Despite the different approach used in developing the CO_2 inventory, several emission sources compare very well with the MOE gridded CO_2 inventory, which adds confidence to our 1988 estimates for the province of Ontario. The SENES CO_2 emissions are 224,372 kt which are approximately 2.5% higher than the MOE/ORTECH inventory. However, the net CO_2 emissions for Ontario are reduced to 42,192 kt because approximately 81% of the total emissions are taken up by CO_2 sinks. This percentage compares reasonably well with the CO_2 emission inventory for British Columbia (B.H. Levelton & Associates, 1990), where 66% of the total emissions were reduced by sinks.

- The inventories for N_2O and CH_4 cannot be judged against anything else because there have been no inventories for these gases compiled to date for the province of Ontario. However, when comparing the contributions of various sources and sinks to other related inventories (e.g. the national inventory by Environment Canada, 1991), these estimates compare reasonably well.

- Table 9.1 summarizes the total sources, total sinks, and net emissions for CO_2, CH_4, N_2O and CFCs for the Province of Ontario.

9.2 RECOMMENDATIONS

- Because of a lack of better information, several emission factors had to be based on assumptions that may not be valid (e.g. CH_4 emissions from the combustion of certain fuels, CO_2 emissions from wood products decay and raw CO_2, etc.). Likewise, sink factors that were used may not be accurate, but were chosen using

TABLE 9.1
1988 NET GREENHOUSE GAS EMISSIONS FOR THE PROVINCE OF ONTARIO (in kilotonnes)

OURCE	CARBON DIOXIDE		NITROUS OXIDE		METHANE		CFCs
	(kt)	(%)	(kt)	(%)	(kt)	(%)	(kt)
TATIONARY FUEL COMBUSTION							
il Products	19,220	8.57	1.22	0.47	0.65	0.04	
atural Gas	41,840	18.65	1.54	0.59	0.99	0.06	
GLs	4,147	1.85	0.20	0.08	0.10	0.01	
oal	48,809	21.75	3.96	1.52	0.35	0.02	
'ood/Waste	9,383	4.18	1.05	0.40	2.02	0.12	
Total	123,400	55.00	8.79	3.37	4.10	0.24	-
RANSPORTATION							
otor Gasoline	29,313	13.06	3.07	1.18	0.91	0.05	
iesel	9,939	4.43	1.47	0.56	0.30	0.02	
viation Turbo	4,236	1.89	0.36	0.14	0.13	0.01	
viation Gas	76	0.03	0.01	0.00	0.00	0.00	
eavy Fuel Oil	784	0.35	0.03	0.01	0.02	0.00	
Total	44,349	19.77	4.95	1.90	1.35	0.08	-
OSSIL FUEL PRODUCTION	2,145	0.96	0.03	0.01	0.67	0.04	-
IDUSTRIAL PROCESSES	6,175	2.75	21.23	8.14	-	-	-
RODUCT USAGE	1	0.00	0.59	0.23	-	-	-
ICINERATION	1,854	0.83	0.28	0.11	7.20	0.43	-
ANDFILLS AND SEWAGE TREATMENT	1,792	0.80	-	-	699.4	41.69	-
RES AND WOOD DECAY	41,172	18.35	1.41	0.54	17.64	1.05	-
GRICULTURE	-	-	1.15	0.44	338.9	20.20	-
AND AND WATER SURFACES							
Soils	-	-	222.80	85.40	-	-	-
Wetlands	-	-	-	-	555.6	33.12	-
Lakes and Reservoirs	-	-	-	-	42.57	2.54	-
Lightning (over Forests)	-	-	0.48	0.18	-	-	-
Forest Harvesting	3,484	1.55	-	-	-	-	-
Total	3,484	1.55	223.27	85.58	598.2	35.65	-
'ILDLIFE	-	-	-	-	9.89	0.59	-
OTAL SOURCES	224,372	100.0	260.9	100.0	1,677	100.0	11.2
INKS							
orests	139,200	76.4	-		560.0	47.5	-
akes	3,885	2.1	-		-	-	-
ivers	8,083	4.4	-		-	-	-
'etlands (peat)	25,397	13.9	-		-	-	-
oil	5,614	3.1	-		-	-	-
ransport to Stratosphere	-	-	16.8	100	-	-	0.7
eaction with OH	-	-	-		564.3	47.8	-
ultivated Land	-	-	-		56.5	4.8	-
OTAL SINKS	182,180	100.0	16.8	100.0	1,181	100.0	0.7
ET EMISSIONS	42,192		244.1		496.5		10.5

personal judgement because of a lack of information. These factors need to be verified through research activities.

- There are many ongoing and planned research studies that will eventually provide information pertinent to this project. Some examples include the CIRAC Northern Wetlands Study, ongoing research projects at Guelph University (on carbon and nitrogen storage and fluxes from soils) and the Forestry Canada/ESSA Ltd. national carbon budget for forests (which includes wetlands).

Tables 4.6, 4.7 and 4.8 can be used as a starting point to identify the following areas for further research:

- CO_2 emissions from landfills, sewage treatment, fires and wood decay.
- CO_2 uptake by lakes and soil.
- N_2O emissions from fires, agriculture, and land and water surfaces.
- N_2O, CH_4 and CFC uptake by global atmospheric processes.
- CH_4 emissions from fires, and land and water surfaces.
- CH_4 uptake by forest soils and cultivated land.

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APPENDIX A

EMISSION FACTOR AND FUEL PROPERTY DATABASES

APPENDIX A: DATA MANAGEMENT

Emission factor data and activity rates in Ontario are taken from three major sources:

1. the Ministry of Energy database on CO_2 emissions;
2. the Ministry of the Environment database on CO_2 and N_2O emissions (ORTECH, 1991); and
3. the literature search.

The Ministry of Energy and Ministry of the Environment databases were obtained by SENES. In addition to these, SENES has created the following databases to record data extracted from the literature search:

1. The Literature Emission Factor database (Litemis.dbf);
2. The Ontario Activity Factor database (Activity.dbf);
3. The Fuel Property database (Fuels.dbf);
4. The Value Ranges database (Ranges.dbf); and
5. The Emission Factor Summary database (Summary.dbf).

These databases are operated using dBASE III Plus software. Details of the data stored in each database is given below.

A.1 THE LITERATURE EMISSION FACTOR DATABASE

The purpose of the Literature Emission Factor database is to store anthropogenic and naturally occurring emission factors for CO_2, N_2O and CH_4 as reported in various literature sources. The following fields are included in each record of this database:

- *Procfuel:* This character field stores a description of the process and/or fuel type that is the source of the emission.

- *Procclass:* This numeric field stores a process class number. Process classes define a category into which the emission source falls. These categories are defined for data organization purposes only. There are eleven process classes defined, however up to ninety-nine classes can be defined.

- *Procdesc:* This character field gives a description of the process category related to the process class number (*procclass*).

- *CO_2emfac:* This numeric field lists the value of the CO_2 emission factor.

- *CO_2unit:* This character field lists the units related to the CO_2 emission factor given in *CO_2emfac*.

- *CO_2srce:* This character field gives a code for the literature source of the emission factor. The literature source code corresponds to the codes used in the Bibliography volumes of this report.

- *N_2Oemfac, N_2Ounit and N_2Osrce:* These fields for N_2O are exactly the same as those described above for CO_2.

- CH_4emfac, CH_4unit and CH_4srce: These fields for CH_4 are exactly the same as those described above for CO_2.

- *Fueldesc:* This character field gives a description of the fuel used for combustible emission sources.

- *Hvused:* This numeric field gives the heating value for the fuel type.

- *Density:* This numeric field gives the density for the fuel type.

- *Fuelsource:* This character field gives the code for the literature source giving fuel heating values and/or densities. The literature source codes correspond with the codes listed in the Bibliography volumes of this report.

- *Sumclass:* This numeric field gives a value to categorize the emission type for summary statistics.

- *Comments:* This character field allows for comments regarding the assumptions made in deciding on the emission factors.

The fuel heating value and the fuel density are used for conversion of emission factor units (for example, from kg pollutant/tonne fuel to kg pollutant/PJ energy from fuel). Consequently, the fuel type description, the fuel heating value, the fuel density and the literature source for the fuel properties is given only for those emission factors that required unit conversions.

Differing emission factors given in the literature that were derived for the same or similar sources are also summarized in the Emission Factor Summary database. This database is described in detail in Section A.5. The summary statistics are based on the emission factors given in the Literature Emission Factor Database. The *Sumclass* field gives a number to define the summary category in which the emission factor belongs. An emission factor derived from the same source was not included in the summary category twice. All repeated emission factor values were assigned the summary class of:

- 997 - for repeated emission factors from the Ministry of Energy database;

- 998 - for repeated emission factors from the Ministry of the Environment database; and

- 999 - for repeated emission factors from the literature sources.

The summary database gives the statistics for all the literature emission factors with the same number. A description of the summary class for each number is also given in the summary database.

A.2 THE ACTIVITY EMISSION FACTOR DATABASE

Ontario activity factors were taken from the Ministry of Energy and the Ministry of the Environment databases. The activity database gives the activity factors from the Ministry of Energy database. For each record in the Activity Emission Factor database, the following fields are defined:

- *Year:* This numeric field gives the base year of the activity factor.
- *Process:* This character field describes the process for which the activity factor is given.
- *Ind_sect:* This character field describes the industrial sector for the process (i.e. industrial, commercial, etc.).
- Value_quan: This numeric field gives the value of the activity factor.
- *Units:* This character field gives the units of the activity factor.
- *Source:* This character field lists the source of the activity factor.
- *Comments:* This character field is reserved for comments related to the activity factor.

A.3 THE FUEL PROPERTY DATABASE

Fuel properties are recorded so that emission factor units can be converted from one form to another. The following information is stored in each record of the fuel property database:

- *Fuel:* This character field gives a description of the fuel.
- *Fuel_form:* This character field gives the fuel formula or the carbon content of the fuel.
- *Density:* This numeric field gives the density of the fuel.
- *HHV:* This numeric field gives the higher heating value (HHV) of the fuel.
- *HHV_units:* This character field gives the units for the higher heating value.
- *LHV:* This numeric field gives the lower heating value (LHV) of the fuel.
- *LHV_units:* This character field gives the units for the higher heating value.
- Source: This character field gives the literature source of the fuel information.

In most cases, the lower heating value of the fuel is used for conversion of emission factor units.

A.4 THE VALUE RANGES DATABASE

In some cases, emission factors, total emissions or activity rates are recorded in the literature giving a range of values. These ranges can be represented by a median value and a percentage above and percentage below the median value. For example, an emission factor recorded as an average value of 2.5 tonne pollutant/PJ with a range of 1.0 - 4.6 tonnes pollutant/PJ can be represented by a median of 2.5 with a range of plus 84% and minus 60%. If median values are not given, the value is assumed to be normally distributed and the middle value of the range is used as a median.

The following data is stored in each record of the Value Ranges Database:

- *Process:* This character field gives a description of the process.
- *Upper:* This numeric field gives the upper value percentage of the range.
- *Lower:* This numeric field gives the lower value of the range.
- *Avg:* This numeric field gives the average or median value of the range.
- *Isavg:* This logical field identifies a flag indicating if the median is a median given in the literature or simply the middle value of a range.
- *Value_ID:* This character field gives a description of the value that the range represents.
- *Units:* This character field gives a description of the units of the range.
- *Year:* This numeric field describes the base year of the information.
- *Source:* This character field gives the source of the information. Literature sources are coded as listed in the Bibliography volumes of this report.

A.5 THE EMISSION FACTOR SUMMARY DATABASE

The Emission Factor Summary Database contains summary statistics for similar emission factors as reported by the literature. The emission factor values used for the summary database are in the Literature Emission Factor database described above. Each record in the Emission Factor Summary database contains the following fields:

- *Sumclass:* This numeric field gives the summary classification for which the summary statistics are given. The summary class in this database corresponds with the summary class used in the Literature Emission Factor Database.
- *Sumdesc:* This character field gives a description of the summary classification corresponding to the summary class number (*sumclass*).
- *Procclass:* This numeric field gives the process class corresponding to that used in the Literature Emission Factor Database for the process or summary category.
- *Procdesc:* This character field gives a description of the process class.
- *CO_2avg:* This numeric field gives the average of the CO_2 emission factors summarized.
- *CO_2max:* This numeric field gives the maximum of the CO_2 emission factors summarized.
- *CO_2min:* This numeric field gives the minimum of the CO_2 emission factors summarized.

- *CO_2std:* This numeric field gives the standard deviation of the CO_2 emission factors summarized.

- *CO_2unit:* This character field gives the unit for the CO_2 summary statistics.

- *CO_2num:* This numeric field gives the number of CO_2 emission factors that were summarized.

- *N_2Oavg, N_2Omax, N_2Omin, N_2Ostd, N_2Ounit and N_2Onum:* These fields for N_2O are identical to those used for CO_2 described above.

- *CH_4avg, CH_4max, CH_4min, CH_4std, CH_4unit and CH_4num:* These fields for CH_4 are identical to those used for CO_2 described above.

APPENDIX B

EMISSIONS FROM LANDFILLS AND WETLANDS

APPENDIX B: EMISSIONS FROM LANDFILLS AND WETLANDS

LANDFILLS

Tables B.1 and B.2 were adapted from B.H. Levelton & Associates (1991). These tables were used in the U.S. EPA Scholl Canyon (Landfill Gas) Model to estimate CO_2 and CH_4 emissions from landfills in Ontario. Table B.3 lists the predicted quantities of waste to be landfilled in the province up to the year 2010.

WETLANDS

Information regarding coverage by wetland type in Tables B.4 and B.5 for three areas in the Eastern Temperature Wetland Region was obtained from Riley (1988). The methodologies used by Roulet et al. (1991) to determine the spatially weighted flux for the Low Boreal Wetland Region were employed for the Eastern Temperate Wetland Region and the calculated spatially weighted flux rate value is given in Table B.5. This rate was used to determine the total methane emissions per year for that wetland region. The wide range of flux values for methane found in the literature is shown in Table B.6 for the Eastern Temperate and Low Subarctic Wetland Regions. Figures B.1, B.2 and B.3 present the GIS outputs.

Table B.1

MSW INCINERATED AND LANDFILLED IN ONTARIO

			Landfilled	
Year	Disposed of (tonnes)	Incinerated (tonnes)	(tonnes)	(%)
1941	1,218,461	0	1,218,461	100
1942	1,249,440	0	1,249,440	100
1943	1,259,412	0	1,259,412	100
1944	1,274,853	0	1,274,853	100
1945	1,286,756	0	1,86,756	100
1946	1,316,673	0	1,316,673	100
1947	1,343,373	0	1,343,373	100
1948	1,375,220	0	1,357,220	100
1949	1,408,354	0	1,408,354	100
1950	1,438,271	0	1,438,271	100
1951	1,478,997	30,000	1,448,997	98
1952	1,540,247	30,000	1,510,247	98
1953	1,589,465	30,000	1,559,465	98
1954	1,645,439	30,000	1,615,439	98
1955	1,694,014	170,463	1,523,551	90
1956	1,738,697	170,466	1,568,231	90
1957	1,813,039	170,461	1,642,578	91
1958	1,872,552	170,450	1,702,102	91
1959	1,920,162	170,430	1,749,731	91
1960	1,965,841	170,451	1,795,390	91
1961	2,046,206	170,486	1,875,721	92
1962	2,125,586	170,499	1,955,087	92
1963	2,212,477	170,483	2,041,994	92
1964	2,308,957	170,431	2,138,527	93

Table B.1, continued

Year	Disposed of (tonnes)	Incinerated (tonnes)	Landfilled (tonnes)	Landfilled (%)
1965	2,410,898	170,367	2,240,531	93
1967	2,633,566	170,600	2,462,966	94
1968	2,737,120	203,726	2,533,394	93
1969	2,839,149	283,479	2,600,671	92
1970	2,961,027	238,265	2,722,762	92
1971	3,171,705	237,953	2,933,752	92
1972	3,376,463	401,313	2,975,149	88
1973	3,590,182	401,180	3,189,001	89
1974	3,838,947	404,123	3,434,824	89
1975	4,090,001	402,999	3,687,002	90
1976	4,343,005	401,017	3,941,988	91
1977	4,609,042	400,269	4,208,774	91
1978	4,889,610	399,269	4,490,340	92
1979	5,171,624	400,338	4,771,286	92
1980	5,473,896	400,248	5,073,648	93
1981	5,509,027	424,720	5,084,307	92
1982	5,558,722	345,619	5,213,103	94
1983	5,619,723	319,252	5,300,471	94
1984	5,685,961	327,141	5,358,820	94
1985	5,752,838	324,383	5,428,455	94
1986	5,820,929	339,931	5,480,998	94
1987	5,918,019	396,925	5,521,094	93
1988	6,024,115	313,863	5,710,252	95
1989	6118,395	258,700	5,859,695	96
1990	6,215,804	258,700	5,957,104	96

Table B.2

PER CAPITA MSW DISPOSAL FACTORS USED IN THIS STUDY

Year	Per Capita Disposal[a] kg/day
1940	0.88
1945	0.88
1950	0.88
1955	0.88
1960	0.88
1965	0.97
1970	1.07
1975	1.37
1980	1.75
1985	1.75
1990	1.75

[a] Interpolate linearly between years stated for those not shown.

Source: B.H. Levelton & Associates, 1991.

Table B.3

WASTE DISPOSAL QUANTITIES ASSUMED FOR LANDFILL GAS MODEL

Year	Population[1]	Waste[2] Generated (tonnes)	Percent[3] Diversion	Disposed[4] (tonnes)	Incinerated[5] (tonnes)	Landfilled[6] (tonnes)
1988	9,431,100			6,024,115*	313,863	5,710,252
1989	9,578,700			6,118,395*	258,700	5,859,695
1990	9,731,200			6,215,804*	258,700	5,957,104
1991	9,906,400	5,532,229	20	4,425,783	258,700	4,167,083
1992	10,074,809	5,626,277	25	4,219,708	258,700	3,961,008
1993	10,246,081	5,721,924	28	4,119,785	258,700	3,861,085
1994	10,420,264	5,819,196	31	4,015,246	258,700	3,756,546
1995	10,597,408	5,918,123	34	3,905,961	258,700	3,647,261
1996	10,735,175	5,995,058	37	3,776,887	258,700	3,518,187
1997	10,874,732	6,072,994	40	3,643,796	258,700	3,385,096
1998	11,016,104	6,151,943	43	3,506,608	258,700	3,247,908
1999	11,159,313	6,231,918	46	3,365,236	258,700	3,106,536
2000	11,304,384	6,312,933	50	3,156,467	258,700	2,897,767
2001	11,417,428	6,376,063	50	3,188,031	258,700	2,929,331
2002	11,531,602	6,439,823	50	3,219,912	258,700	2,961,212
2003	11,646,918	6,504,221	50	3,252,111	258,700	2,993,411
2004	11,763,387	6,569,264	50	3,284,632	258,700	3,025,932
2005	11,881,021	6,634,956	50	3,317,478	258,700	3,058,778
2006	11,999,831	6,701,306	50	3,350,653	258,700	3,091,953
2007	12,119,830	6,768,319	50	3,384,159	258,700	3,125,459
2008	12,241,028	6,836,002	50	3,418,001	258,700	3,159,301
2009	12,363,438	6,904,362	50	3,452,181	258,700	3,193,481
2010	12,487,073	6,973,406	50	3,486,703	258,700	3,228,003

* Taken from B.H. Levelton & Associates, 1991.

1988-1991 population figures obtained from Statistics Canada (personal communication, 1991). Forecast populations based on forecast parameters provided by Erik Haites of Barakat & Chamberlin for this project.

The average waste generation rate derived from MOE (1991) for residential and commercial was 1.53 kg/capita/day for 1989, and was assumed to stay constant through to 2010.

Based on the waste reduction goals of 25% by 1992 and 50% by 2000, these waste diversion percentages were assumed.

Amount disposed = (waste generated x population) - amount diverted.

Amount incinerated obtained from B.H. Levelton & Associates (1991) and assumed to be constant.

Amount landfilled = amount disposed - amount incinerated.

Table B.4

COVERAGE BY WETLAND TYPE - AREAS IN EASTERN TEMPERATE WETLAND REGION

Region	Area Mapped (ha)	Bogs	Fens	Conifer Swamps	Hardwood/Mixed Swamps	Thicket Swamps	Marshes	Percent of Total Area
Peterborough	1,000,000	1.4	1.4	29.2	40.4	12.3	15.3	5.6
Kingston-Belleville	1,200,000	0.6	0.1	7.9	50.9	34.2	6.2	8.8
Ottawa-Brockville	630,000	2.2	4.2	5.8	43.1	39.9	4.7	15.5
TOTAL	2,830,000							
MEANS		1.4	1.9	14.3	44.8	28.8	8.7	10.0

Source: Peat and Peatland Resources of Southeastern Ontario (Riley, 1988).

Table B.5

DETERMINATION OF SPATIALLY WEIGHTED FLUX RATE FOR EASTERN TEMPERATE WETLAND REGION

Wetland Type	$(g\ CH_4/m^2/y)$ Annual Flux	Fraction of Wetlands	$g\ CH_4/m^2/y$ Spatially Weighted Flux
Bogs	1.746	.014	0.024
Fens	0.359	.019	0.007
Conifer Swamps	0.180	.143	0.026
Hardwood/Mixed Swamps	0.097	.448	0.043
Thicket Swamps	4.748	.288	1.367
Marshes	0.110	.087	0.010
			1.477

Table B.6

AVERAGE FLUX VALUES OF METHANE FOR VARIOUS HABITAT TYPES IN EASTERN TEMPERATE AND LOW SUBARCTIC WETLAND REGIONS

Wetland Region	Location	Habitat Type	Average Flux $mg/m^2/d$ (Range)	Reference
Eastern Temperate	Minnesota	forested bog	77	Crill et al. 1988
		open bog	294	
		acid bog	102	
		forested fen	142	
		peatland fen-open water	325	
		temperate bog	1.1 - 9.6	Yavitt et al., 1990 (in Roulet et al., 1991)
		temperate swamps	0 to 200	
	Northern Minnesota	bogs and fens	337 (3-1940)	Harriss et al. 1985
	Marcel Experimental Forest, Minnesota	forested bog	30 (1-117)	Crill et al. 1988
		unforested bog	201 (9-668)	
		fen	95 (22-264)	
	Mt. St. Hilaire, St. Bruno, Quebec	swamps (deciduous)	1.9 - 21.1	Moore and Knowles, 1988 *
		drained swamp	1.1	
		domed bog	1.1	
		flat bog	0.5	

Table B.6, Cont'd

Wetland Region	Location	Habitat Type	Average Flux $mg/m^2/d$ (Range)	Reference
Low Subarctic	Quebec	fen margin	65	Moore et al., 1990
		central fen	125	
		flooded fen	36	
		fen-June to August average	18	
		fen	7-214	Moore and Roulet, 1991
		fen	0 to >27.4	Roulet et al. 1991
	Northern Alaska	wet coastal tundra	119 (12-389)	Sebacher et al., 1986
		moist coastal tundra	5 (BD-20)[1]	
		tussock tundra	40 (BD-120)	
		alpine fen	289 (268-343)	
		boreal marsh	106 (86-122)	
	Schefferville (N. Quebec)	subarctic fens-rich	10.4	Moore & Knowles, 1988 *
		subarctic fens-poor	24.7	
		subarctic string-(fen)	3.8	
		subarctic shallow pool (fen)	18.1	
		subarctic deep pool (fen)	15.6	

* Values converted from $g/m^2/y$.

[1] BD = Below the detectable limit of equipment used.

APPENDIX C

UNCERTAINTIES IN GWP CALCULATIONS

Based on:
Henry Hengeveld, "Global Warming Potential:
Concept, Uncertainties and Application",
mimeo, August, 1991

and

L.D. Danny Harvey, "A Guide to Global Warming Potentials",
mimeo, November, 1991

APPENDIX C: UNCERTAINTIES IN GWP CALCULATIONS

C.1 INTRODUCTION

GWPs are calculated by estimating the average (over a specified integration period) global heating effect of the radiation trapped by the release of a particular greenhouse gas at the tropopause (the base of the stratosphere) relative to the effect of a similar release of carbon dioxide and integrating this estimate over time. This depends on:

- the absorption and emission coefficients as a function of the gas quantity, pressure, temperature and wavelength, which can be determined to high accuracy from laboratory spectroscopic measurements;
- the degree of overlap in the absorption of the gas in question with absorption by other gases, and hence the concentrations of all other gases; and
- the atmospheric temperature profile and cloudiness.
- the atmospheric lifetimes of carbon dioxide and the gas in question.

The absorption coefficients of many greenhouse gases are not a linear function of concentration, so the radiative heating of a unit of a given gas depends on the existing background concentration of the gas at the time of its release, and changes over time. The radiative heating of a given gas also depends on the concentrations of other gases which absorb in the same spectral regions. For these reasons the heat trapping ability of a gas depends on the future concentrations of most or all of the greenhouse gases. All calculations to date have used the heat trapping ability of each gas appropriate for current conditions and assumed that it does not change over time.

During a recent IPCC workshop on the GWP concept (London, July, 1991), scientists emphasized the need to fully understand the uncertainties associated with calculating GWPs to help avoid misuse of the concept in policy applications. The following sections summarize some of the uncertainties and their implications for estimating GWPs.

C.2 CO_2 ATMOSPHERIC RESIDENCE TIME

Since CO_2 is the standard against which each of the other greenhouse gases is assessed to determine its GWP value, any error in calculating the radiative forcing or atmospheric lifetime of CO_2 will affect all absolute (although not relative) GWP values for the other greenhouse gases. While the radiative forcing of CO_2 is comparatively well understood, its atmospheric lifetime is not.

Unlike the other greenhouse gases, which are normally destroyed in the atmosphere through chemical reactions with other constituents, CO_2 is removed from the atmosphere primarily through photosynthetic processes or direct absorption into water. The volume of CO_2 removed annually from the atmosphere into the ocean and biosphere is very large - sufficient to remove all CO_2 from the atmosphere about every 4 years. However, almost all of the CO_2 removed finds its way back into the atmosphere over variable time periods through biological respiration and decay, or ocean out-gasing. Hence its removal is only temporary.

Ultimately, about 85 percent of the initial release of CO_2 is removed by mixing into the ocean, but only over a period of several hundred to a thousand years. Another 10 percent will be removed by dissolution of marine carbonate sediments over a period of several thousand years. The remaining 5 percent or so is removed over a period of 100,000 years through silicate rock weathering.

Hence the removal of one kg of carbon dioxide injected into the atmosphere does not follow a simple exponential decay curve, but must be estimated with the use of ocean models that simulate the flux of carbon into the deep ocean. The first fraction of the emission decays quite rapidly into the surface ocean, but the decay becomes progressively slower as the processes controlling the transfer from surface to deep oceans, sediments and silicate rock take over. Hence carbon dioxide does not have a finite atmospheric lifetime. In contrast, each of the other greenhouse gases is normally assigned a single lifetime defined by the ratio of atmospheric content to removal rate.

As a result, CO_2 is assigned a range of years - from about 50 to 200 - to describe its mean "lifetime" in the atmosphere (i.e., the time required for the atmospheric concentration of the gas to adjust to an abrupt change in emission rates). Since the ocean models used to estimate the range of CO_2 "lifetimes" are still very imperfect, these estimates can be expected to change as such models become more accurate. The "lifetime" chosen for CO_2 affects the GWPs of all greenhouse gases, but does not change the relative GWPs of the other gases.

C.3 DIRECT RADIATIVE FORCING OF GREENHOUSE GASES

Well-Mixed Gases: The radiative properties of greenhouse gases can vary with altitude, latitude, and season. The GWP concept uses a single value for the radiative forcing of a molecule of each of the greenhouse gases regardless of altitude, latitude and season. Although it has been challenged by a recent study, this is believed to be reasonably valid for well mixed gases because a given molecule has an equal probability of being found at any altitude or latitude in any season.

However, the radiative forcing for a unit of a particular gas released into the atmosphere will change if the composition of the atmosphere changes. The radiative forcing of a specific emission depends on the extent to which the radiation windows within which the gas is emitted are saturated. The higher the concentration of the gas in the atmosphere, the greater the saturation and the lower the radiative forcing, resulting in a further increase in concentration. For example, CFC concentrations in the atmosphere are still very low, and hence their radiative windows are so open that the radiative effects of a unit emission once their concentrations are doubled will be almost identical to that of today. However, CO_2 is already sufficiently abundant in the atmosphere to saturate most of the radiative windows in which it is active. Thus, the radiative forcing per unit of its emissions will decrease as total concentrations increase. Hence, the radiative forcing of CFCs relative to CO_2 can change as the total atmospheric concentrations of these gases change with time. That is, GWP values for CFCs (and other gases) for future years (e.g., 2030) will be different from those of today.

Short-Lived Gases. While the above assumptions with respect to relative radiative forcing may be reasonably accurate for well-mixed gases, that is not so for short-lived atmospheric gases that are not well-mixed (e.g., ozone). These gases do not remain in the atmosphere long enough to spread uniformly throughout the earth's atmosphere, hence they become concentrated in regions close to their source. Their concentrations also usually vary substantially with altitude, and often depend on the seasonal characteristics of the chemical reactions involved in their formation and breakdown, or the combination of chemicals present at a given time or place. Thus, for example, the relative radiative forcing for ozone produced over Toronto may be significantly different from that over Los Angeles, or that generated in the upper troposphere as a result of aircraft transport. Hence, it is very difficult to assign a single representative value to the relative radiative forcing component of GWP indices for such gases.

C.4 INDIRECT RADIATIVE EFFECTS OF ATMOSPHERIC GASES

Greenhouse Gas Precursors. Some gases released into the atmosphere by human activities indirectly influence the radiation balance of the atmosphere by producing greenhouse gases through chemical reactions involving other atmospheric constituents. Such parent gases are commonly referred to as greenhouse gas precursors. Most important among these gases are tropospheric ozone precursors, particularly nitrogen oxides (NO_x), volatile organic compounds (VOCs), and carbon monoxide (CO). In general, these gases and their greenhouse gas by-products are short-lived, and hence their indirect effects are affected by the same range of regional, altitudinal and temporal dependencies identified for direct effects. Although GWP values for indirect effects can usually be estimated, such calculations must allow for an additional element of uncertainty beyond those for direct effects discussed above — that is, the inadequate understanding of the often complex chemical reactions that produce the greenhouse gas by-product. The chemistry involved can be very dependent on the combination of gases present, as well as factors such as light intensity, air temperature, etc. For example, increases in CO and VOCs can result in decreased ozone concentration when low concentrations of NO_x are present, but in significant increases in ozone when NO_x is present in high concentrations.

Some greenhouse gas precursors (e.g., methane) are themselves quite potent greenhouse gases.

In such cases, calculation of GWP values should include both direct and indirect effects, with due consideration of the additional element of uncertainty of the indirect effects due to the atmospheric chemistry involved.

Greenhouse Gas Destroyers. Greenhouse gas precursors indirectly affect radiative forcing by contributing to increased concentrations of greenhouse gases. However, other atmospheric gases indirectly affect such forcing by contributing to the decrease in concentrations of (other) greenhouse gases. In such cases, the indirect effect is a cooling influence on climate. Particularly important in this category is the role of CFCs in destroying ozone in the lower stratosphere and upper troposphere, where it is most effective as a greenhouse gas. Again, when assessing the GWP values for such greenhouse gas destroyers, both the direct and indirect effects, together with their related uncertainties, need to be considered.

C.5 CALCULATING SPECIFIC GWPS

Despite the uncertainties that are still inherent in calculating GWPs, the IPCC considered the evaluation of greenhouse warming potentials of sufficient importance to provide some preliminary estimates of GWPs in its 1990 Scientific Assessment report. In a subsequent IPCC workshop held in the U.K. in July, 1991, these estimates were re-evaluated.

Carbon Dioxide

Direct Effects. Since carbon dioxide is the reference gas for calculating GWPs, the GWP for the direct effects of carbon dioxide is always 1.

Observations from polar ice cores indicate that the atmospheric CO_2 concentration was close to constant for several hundred years prior to the industrial revolution. Since 1800, the atmospheric CO_2 concentration has increased by 25 percent. There is no doubt that this increase is due to anthropogenic activities. However, the observed increase - the so-called airborne fraction - is only about half of the cumulative emissions since 1800. The remaining 50 percent has already been absorbed by some combination of the oceans and terrestrial biosphere. Unfortunately, we are not able to determine the relative importance of these two sinks. Some evidence indicates that the oceans could not have absorbed more than one-third of the non-airborne fraction, implying that the biosphere has absorbed most of the rest. Other evidence suggests that the biosphere has not absorbed most of the non-airborne fraction.

Determination of the current sinks and how these sinks are likely to change with increasing CO_2 emissions, is crucial to the calculation of GWPs. If the primary sink is the terrestrial biosphere, then the continuing forest destruction, nutrient limitations or temperature-induced increases of respiration could dramatically increase the lifetime of CO_2 in the atmosphere. If the primary sink is the oceans, then global warming-induced changes in ocean circulation or biological productivity could significantly alter the atmospheric lifetime of CO_2. Uncertainty in the removal rates of CO_2 from the atmosphere is perhaps the biggest source of uncertainty in the calculation of GWPs over the next few decades.

Indirect Effects. While CO_2 is neither significant as a greenhouse gas precursor or destroyer, its increasing atmospheric concentration can cool stratospheric temperatures. Lower temperatures in the stratosphere slow down natural ozone destruction by gaseous phase chemistry. This increases the stratospheric ozone layer and reduces the quantity of ultraviolet radiation reaching the Earth's surface. This means that increasing CO_2 concentrations have an indirect warming effect by increasing the stratospheric ozone layer.

On the other hand, cooling the stratosphere increases the area where the temperature conditions necessary for ozone depletion through aqueous phase chemistry can occur. The Antarctic ozone hole depends on nitric acid water droplets which require a temperature of -80°C. Cooling the stratosphere increases the area where the necessary temperatures are met and hence may lead to destruction of the ozone layer over a larger area. Such destruction of stratospheric ozone means that less heat is trapped, thus creating an indirect cooling effect. This cooling effect could be significant; indeed, estimates for the 1978-1988 period suggest that ozone depletion masked half of the global warming due to rising concentrations of greenhouse gases during this period.

The magnitudes of these indirect effects are difficult to estimate, so it is not clear whether the indirect cooling or warming effect would be larger.

Methane

Direct Effects. Rate of removal of methane from the atmosphere, and hence its atmospheric lifetime, is the primary uncertainty in calculating its GWP value for direct effects.

Although methane's lifetime is generally estimated to be about 10 years, this value has an error range of +/- 25 percent. Recent research results suggest that a value closer to the upper part of that range may be more accurate. If so, current estimates for GWP value of methane's direct effects, may be too low by as much as 25 percent. Because its lifetime is comparatively short, most of the accumulated radiative effects of a sudden addition of methane into the atmosphere would occur within the first few decades after release. By comparison, after a few decades most of a similar emission of CO_2 would still remain in the atmosphere and continue to affect the radiative balance. Hence, GWPs for the direct effects of methane are much higher when integrated over 20 years (GWP of about 27) than over a one century (GWP = 6) or longer period of time (over 500 years, GWP = 2).

Indirect Effects. Oxidation of methane in the atmosphere results in the production of carbon dioxide. This indirect effect is comparatively small (because of the much lower GWP value of CO_2) but long-lasting (because of CO_2's long lifetime) and well understood. The methane oxidation also produces water vapour (which is particularly potent as a greenhouse gas in the lower stratosphere), and indirectly affects concentrations of ozone precursors in the troposphere by reducing the atmospheric concentration of one of their principal scavengers, the OH radical.

The OH concentration depends in complex ways on emissions of methane, whose lifetime depends on the OH concentration, thus introducing a feedback between methane concentration and its GWP. Most models suggest that present increases in atmospheric methane have decreased the abundance of the OH radical in the Southern Hemisphere, but increased its abundance in the Northern Hemisphere.

These indirect effects of methane have large uncertainties and, particularly with respect to the OH effect, are variable in space and time. Although the 1990 GWP values reflected these indirect effects, the IPCC is now less sure of the results and the 1992 values do not reflect indirect effects. Even though indirect methane GWPs have not been calculated, some of the indirect effects are extremely important and it is likely that the total GWPs for methane (direct and indirect) will be substantially higher than the values shown in Table 7.4.

Nitrous Oxide

Direct Effects. As with methane, the greatest uncertainties associated with calculating GWPs for direct radiative effects of releases of nitrous oxide into the atmosphere are related to its atmospheric lifetime. We cannot at present balance the N_2O budget, thus giving rise to different estimates of the rate at which it is removed from the atmosphere. Estimates of the removal rate for N_2O from the atmosphere (and hence lifetime) vary by almost a factor of two. A similar uncertainty therefore applies to its GWP value.

Because the lifetime estimates for nitrous oxide (150 years) are of similar magnitude to that of CO_2, the GWP values are much less dependent on integration period than those of methane. GWP values for N_2O vary from 270-290 for integration periods of 20 to 100 years, to 190 for a 500-year integration period.

Indirect Effects. The primary process for nitrous oxide removal from the atmosphere is photochemical decomposition in the stratosphere. The NO molecules that result from this process become catalysts for ozone breakdown in the stratosphere. Since decreased ozone in the lower stratosphere also decreases net radiative forcing, this effect of N_2O emissions would be negative. Hence, net GWP values for nitrous oxide should be somewhat lower than that of direct effects only. The magnitude of the effect has not as yet been estimated.

Halocarbons

Direct Effects: CFCs, HCFCs and HFCs have no natural sources, and estimates of their release into the atmosphere through human activities are reasonably accurate. Their long lifetimes also allow them to become well-mixed throughout the troposphere. Hence the GWP values for their direct radiative forcing effect can be calculated with considerable reliability, although subject to uncertainties relating to the lifetime of the CO_2 reference gas.

As with nitrous oxide, lifetimes of CFCs (60 to 400 years) are broadly similar to that of CO_2. Hence the variability of GWP values with different integration times is significantly less than for methane, although for some, greater than for nitrous oxide. GWP values for direct effects of CFCs, integrated over 100 years, vary from 7300 for CFC-12 to 3500 for CFC-11.

HCFCs and HFCs generally have much shorter lifetimes (less than 30 years), and hence the GWPs decrease substantially as length of the integration period increases. Values for HCFC-22 (lifetime of 15 years), for example, decrease from 4100 at 20 years, to 1500 at 100 years and 510 at 500 years.

Indirect Effects. The primary indirect effect of CFCs on the radiative forcing in the atmosphere is caused by the depletion of ozone in the lower stratosphere and upper troposphere that occurs following the photochemical decomposition of these gases. Depletion of ozone in this region of the atmosphere produces a significant negative radiative forcing on the climate system. While the magnitude of these effects is difficult to estimate, preliminary investigations suggest they are strongly latitude-dependent and may be large enough to fully offset the direct radiative effects of CFCs.

Based on TOMS satellite data used to estimate changes in total vertical column ozone concentrations during the past decade, studies suggest that the radiative forcing due to these changes is positive in tropical regions and increasingly negative poleward of the 20 degree latitude line in both hemispheres. In mid-to-high latitudes, the negative forcing appears to exceed the positive forcing due to the direct effects of CFC increases over the same period of time.

If all the change in ozone concentrations were due to CFC decomposition, then the net effects of CFCs on radiative forcing (direct + indirect) may be strongly positive in the tropics and negative over polar regions. This not only implies that net GWPs for CFCs will be extremely difficult to calculate, but that the non-uniform radiative forcing may be offsetting polar amplification of global warming due to other greenhouse gases.

Because of their substantially lower potential for depleting the ozone layer, the indirect effects of HCFCs and HFCs would be similar in nature to, but much less significant than that of CFCs. The HCFCs are destroyed principally by reaction with tropospheric OH, so their life time will change in response to changing OH concentration.

NO_x, CO and VOCs

Releases of these gases into the atmosphere do not have significant direct effects on radiative forcing of the climate system. However, because these gases decompose in the atmosphere through chemical reactions that produce greenhouse gases as a by-product, they can have substantial indirect effects. The two principal greenhouse gases produced by these gases are ozone and carbon dioxide. As well, CO depletes OH in some regions thereby extending the lifetime of methane. While calculating GWP values for the indirect effects that occur as a result of carbon dioxide production is relatively simple and reliable, this is not the case for ozone.

Indirect Effects Through CO_2. Carbon dioxide produced by the decay of CO and VOCs behaves physically and radiatively like CO_2 directly emitted by human activities. Since the GWP for CO_2 is 1, related GWP values for the above gases are simply determined by calculating the mass of CO_2 produced from the decay of 1 kg of gas emitted. These values are 2 and 3 for CO and VOCs, respectively, and are constant with different integration periods.

Indirect Effects Through Ozone. Ozone is a very potent greenhouse gas, and its production as a by-product of the chemical decay of other gases such as NO_x, CO and VOCs is a very important indirect effect of those gases on the climate system. However, calculating GWP values for these indirect effects is extremely difficult for two reasons. First, the chemical processes are highly dependent on temperature (season), the combination of gases present, and the amount of ambient solar light available. As mentioned earlier, the concentration of NO_x present is particularly critical. Secondly, the short lifetimes of these precursor gases and their ozone by-product prevent thorough mixing in the atmosphere, both vertically and horizontally. Hence concentrations of low level ozone are highly variable in both space and time.

These variabilities make the calculation of global GWP values to represent indirect ozone effects of precursor gases complex and very unreliable at best. The related GWP value for NO_x released in Toronto in July, for example, would be substantially different from that for releases in January, or similar releases in northern Ontario. Likewise releases in other parts of the world in different seasons would each have their unique GWP value. During the recent IPCC workshop on the GWP concept, scientists unanimously agreed that past efforts to estimate single global GWP values for ozone related indirect effects of emissions of the above gases were inappropriate, resulting in misrepresentative values. Furthermore, more accurate numbers are unlikely to be forthcoming. That is, in the case of ozone precursors, the GWP concept appears to be an inappropriate tool to assess the true potential of emissions to affect climate.

The above may not apply to emissions of NO_x directly into the upper troposphere by aircraft. These emissions are believed to contribute to depletion of ozone concentrations in this region and will have a cooling influence. The magnitude of this influence is not well known and hence is difficult to estimate.

APPENDIX D

INDIVIDUALS CONTACTED TO DATE

APPENDIX D: INDIVIDUALS CONTACTED

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APPENDIX E

MISCELLANEOUS TABLES

TABLE E.1
ONTARIO GLOBAL WARMING GAS EMISSION COEFFICIENTS
EMISSIONS FROM FUEL IMPORTED TO ONTARIO

EMISSION COEFFICIENT SUMMARY
(tonne emission per PJ fuel delivered to Ontario)

	Carbon Dioxide	Methane	Nitrous Oxide
Combustion emissions			
Western Canada coal	1,319	0.004	0.034
Pennsylvania coal	1,162	0.016	0.030
Western Canada crude/synthetic oil	9,071	0.124	0.158
Western Canada natural gas	10,035	0.227	0.102
Uranium	11,287	0.092	0.257
US electricity	252,069	1.460	6.007
Fugitive emissions			
Western Canada coal		41.140	
Pennsylvania coal		522.191	
Western Canada crude/synthetic oil			
Western Canada natural gas		58.939	
Uranium			
US electricity			
Total emissions			
Western Canada coal	1,319	41.145	0.034
Pennsylvania coal	1,162	522.207	0.030
Western Canada crude/synthetic oil	9,071	0.124	0.158
Western Canada natural gas	10,035	59.166	0.102
Uranium	11,287	0.092	0.257
US electricity	252,069	1.460	6.007

TABLE E.1
ONTARIO GLOBAL WARMING GAS EMISSION COEFFICIENTS
EMISSIONS FROM FUEL IMPORTED TO ONTARIO

EMISSION COEFFICIENT SUMMARY
(lb emission per MMBtu fuel delivered to Ontario)

	Carbon Dioxide	Methane	Nitrous Oxide
Combustion emissions			
Western Canada coal	3.078	0.000010	0.000079
Pennsylvania coal	2.712	0.000038	0.000070
Western Canada crude/synthetic oil	21.168	0.000291	0.000368
Western Canada natural gas	23.416	0.000531	0.000238
Uranium	26.337	0.000216	0.000600
US electricity	588.196	0.003408	0.014018
Fugitive emissions			
Western Canada coal		0.096000	
Pennsylvania coal		1.218519	
Western Canada crude/synthetic oil			
Western Canada natural gas		0.137532	
Uranium			
US electricity			
Total emissions			
Western Canada coal	3.078	0.096010	0.000079
Pennsylvania coal	2.712	1.218556	0.000070
Western Canada crude/synthetic oil	21.168	0.000291	0.000368
Western Canada natural gas	23.416	0.138063	0.000238
Uranium	26.337	0.000216	0.000600
US electricity	588.196	0.003408	0.014018

TABLE E.1
ONTARIO GLOBAL WARMING GAS EMISSION COEFFICIENTS
EMISSIONS FROM FUEL IMPORTED TO ONTARIO

	FUEL CONSUMED IN FUEL CYCLE							
	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
FUEL CYCLE ENERGY INTENSITY								
(Btu consumed per Btu delivered)								
Western Canada coal								
Extraction	0.0000	0.0000	0.0000	0.0000	0.0005	0.0010	0.0000	0.0015
Transportation				0.0138				0.0138
Total	0.0000	0.0000	0.0000	0.0138	0.0005	0.0010	0.0000	0.0153
Pennsylvania coal								
Extraction	0.0005	0.0000	0.0040	0.0004	0.0000	0.0000	0.0027	0.0076
Transportation				0.0026				0.0026
Total	0.0005	0.0000	0.0040	0.0030	0.0000	0.0000	0.0027	0.0102
Western Canada crude/synthetic oil								
Extraction	0.0000	0.0154	0.0000	0.0050	0.0734	0.0046	0.0000	0.0983
Flaring					0.0007			0.0007
Transportation						0.0078		0.0078
Total	0.0000	0.0154	0.0000	0.0050	0.0741	0.0124	0.0000	0.1068
Western Canada natural gas								
Extraction/processing	0.0000	0.0000	0.0000	0.0000	0.0882	0.0056	0.0000	0.0938
Flaring					0.0061			0.0061
Transportation					0.0754			0.0754
Total	0.0000	0.0000	0.0000	0.0000	0.1697	0.0056	0.0000	0.1753
Uranium								
Extraction/refining	0.0000	0.0000	0.0000	0.0008	0.0170	0.0000	0.0463	0.0640
Total	0.0000	0.0000	0.0000	0.0008	0.0170	0.0000	0.0463	0.0640
Electricity								
Michigan total	2.4927	0.0000	0.0586	0.0100	0.0074			2.5687
Alberta total	2.8331	0.0000	0.0000	0.0000	0.1538			2.9870
Pennsylvania total	2.1308	0.0137	0.1426	0.0232	0.0083			2.3185
END USE EMISSION COEFFICIENTS								
(lb emitted/MMBtu consumed)								
Carbon (CO2)	231.0	220.3	166.9	170.6	115.9	672.3	524.0	
Methane (CH4)	0.0012	0.0012	0.0067	0.0004	0.0030	0.0039	0.0036	
Nitrous Oxide (N2O)	0.0055	0.0055	0.0049	0.0045	0.0009	0.0157	0.0126	

TABLE E.1
ONTARIO GLOBAL WARMING GAS EMISSION COEFFICIENTS
EMISSIONS FROM FUEL IMPORTED TO ONTARIO

	FUEL CONSUMED IN FUEL CYCLE							
	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
CARBON DIOXIDE FUEL CYCLE COMBUSTION COEFFICIENTS								
(lb CO2/MMBtu delivered)								
Western Canada Coal								
Extraction	0.00	0.00	0.00	0.00	0.06	0.67	0.00	0.73
Transportation	0.00	0.00	0.00	2.35	0.00	0.00	0.00	2.35
Total	0.00	0.00	0.00	2.35	0.06	0.67	0.00	3.08
Pennsylvania Coal								
Extraction	0.12	0.00	0.66	0.07	0.01	0.00	1.41	2.27
Transportation	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.44
Total	0.12	0.00	0.66	0.52	0.01	0.00	1.41	2.71
Western Canada crude/synthetic oil								
Extraction	0.00	3.38	0.00	0.85	8.51	3.12	0.00	15.86
Flaring	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08
Transportation	0.00	0.00	0.00	0.00	0.00	5.22	0.00	5.22
Total	0.00	3.38	0.00	0.85	8.59	8.35	0.00	21.17
Natural Gas								
Extraction/processing	0.00	0.00	0.00	0.00	10.22	3.74	0.00	13.97
Flaring	0.00	0.00	0.00	0.00	0.71	0.00	0.00	0.71
Transportation	0.00	0.00	0.00	0.00	8.74	0.00	0.00	8.74
Total	0.00	0.00	0.00	0.00	19.67	3.74	0.00	23.42
Uranium								
Extraction/refining	0.00	0.00	0.00	0.13	1.97	0.00	24.24	26.34
Total	0.00	0.00	0.00	0.13	1.97	0.00	24.24	26.34
Electricity								
Michigan total	575.86	0.00	9.79	1.70	0.85			588.20
Alberta total	654.49	0.00	0.00	0.00	17.84			672.33
Pennsylvania total	492.24	3.02	23.81	3.95	0.96			523.97

TABLE E.1
ONTARIO GLOBAL WARMING GAS EMISSION COEFFICIENTS
EMISSIONS FROM FUEL IMPORTED TO ONTARIO

	FUEL CONSUMED IN FUEL CYCLE							
	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
METHANE FUEL CYCLE COMBUSTION COEFFICIENTS								
(lb CH4/MMBtu delivered)								
Western Canada coal								
Extraction	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001
Transportation	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
Total	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
Pennsylvania coal								
Extraction	0.00000	0.00000	0.00003	0.00000	0.00000	0.00000	0.00001	0.00004
Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Total	0.00000	0.00000	0.00003	0.00000	0.00000	0.00000	0.00001	0.00004
Western Canada crude/synthetic oil								
Extraction	0.00000	0.00002	0.00000	0.00000	0.00022	0.00002	0.00000	0.00026
Flaring	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00003	0.00000	0.00003
Total	0.00000	0.00002	0.00000	0.00000	0.00022	0.00005	0.00000	0.00029
Western Canada natural gas								
Extraction/processing	0.00000	0.00000	0.00000	0.00000	0.00026	0.00002	0.00000	0.00029
Flaring	0.00000	0.00000	0.00000	0.00000	0.00002	0.00000	0.00000	0.00002
Transportation	0.00000	0.00000	0.00000	0.00000	0.00023	0.00000	0.00000	0.00023
Total	0.00000	0.00000	0.00000	0.00000	0.00051	0.00002	0.00000	0.00053
Uranium								
Extraction/refining	0.00000	0.00000	0.00000	0.00000	0.00005	0.00000	0.00016	0.00022
Total	0.00000	0.00000	0.00000	0.00000	0.00005	0.00000	0.00016	0.00022
Electricity								
Michigan total	0.00299	0.00000	0.00039	0.00000	0.00002			0.00341
Alberta total	0.00340	0.00000	0.00000	0.00000	0.00046			0.00386
Pennsylvania total	0.00256	0.00002	0.00095	0.00001	0.00002			0.00356

TABLE E.1
ONTARIO GLOBAL WARMING GAS EMISSION COEFFICIENTS
EMISSIONS FROM FUEL IMPORTED TO ONTARIO

	FUEL CONSUMED IN FUEL CYCLE							
	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
NITROUS OXIDE FUEL CYCLE COMBUSTION COEFFICIENTS								
(lb N2O/MMBtu delivered)								
Western Canada coal								
Extraction	0.00000	0.00000	0.00000	0.00000	0.00000	0.00002	0.00000	0.00002
Transportation	0.00000	0.00000	0.00000	0.00006	0.00000	0.00000	0.00000	0.00006
Total	0.00000	0.00000	0.00000	0.00006	0.00000	0.00002	0.00000	0.00008
Pennsylvania coal								
Extraction	0.00000	0.00000	0.00002	0.00000	0.00000	0.00000	0.00003	0.00006
Transportation	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
Total	0.00000	0.00000	0.00002	0.00001	0.00000	0.00000	0.00003	0.00007
Western Canada crude/synthetic oil								
Extraction	0.00000	0.00008	0.00000	0.00002	0.00007	0.00007	0.00000	0.00025
Flaring	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00012	0.00000	0.00012
Total	0.00000	0.00008	0.00000	0.00002	0.00007	0.00019	0.00000	0.00037
Western Canada natural gas								
Extraction/processing	0.00000	0.00000	0.00000	0.00000	0.00008	0.00009	0.00000	0.00017
Flaring	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00001
Transportation	0.00000	0.00000	0.00000	0.00000	0.00007	0.00000	0.00000	0.00007
Total	0.00000	0.00000	0.00000	0.00000	0.00015	0.00009	0.00000	0.00024
Uranium								
Extraction/refining	0.00000	0.00000	0.00000	0.00000	0.00002	0.00000	0.00058	0.00060
Total	0.00000	0.00000	0.00000	0.00000	0.00002	0.00000	0.00058	0.00060
Electricity								
Michigan total	0.01368	0.00000	0.00029	0.00005	0.00001			0.01402
Alberta total	0.01555	0.00000	0.00000	0.00000	0.00014			0.01569
Pennsylvania total	0.01169	0.00008	0.00069	0.00011	0.00001			0.01258

NOTES:

1.Fuel cycle energy intensity

a. Fuel production data

1988 Alberta coal	
1988 Canadian coal production	63.6 Megatonnes (includes metalurgical)
Alberta share	80%
Conversion factors	
lb/tonne	2,210
Btu/lb	12,500
Converted Alberta production	1,406 TBtu
1982 US coal (proxy for Pennsylvania)	
1982 US coal production	18,640 TBtu
1988 Alberta oil	
1988 Alberta crude production.	52,670 thousand cubic meters
Conversion factors	
cubic foot/cubic meter	35.32
gallon/cubic foot	7.484
Btu/gallon	150,000
Converted Alberta production	2,088 TBtu
1988 Alberta oil sands	
1988 Canadian sands production	10,877 thousand cubic meters
Alberta share	100%
Converted Alberta production	431 TBtu
(same conversion factors as oil)	
1987 Alberta natural gas	
1987 Alberta gas production	69,637 million cubic meters
Conversion factors	
cubic foot/cubic meter	35.32
Btu/cubic foot	1,000
Converted Alberta production	2,460 TBtu

b. Extraction/refining energy requirements and intensity

	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
Coal extraction								
Basis: 1988 Alberta								
Energy consumed (TBtu)					0.7	1.4		2.1
Fuel produced (TBtu)								1,406
Energy intensity (Btu/Btu)					0.0005	0.0010		0.0015
Coal extraction								
Basis: 1982 United States								
Energy consumed (TBtu)	9.45		73.81	7.91	0.84		50.25	142.26
Fuel produced (TBtu)								18,640
Energy Intensity (Btu/Btu)	0.0005		0.0040	0.0004	0.0000		0.0027	0.0076
Crude oil extraction								
Basis: 1988 Alberta								
Energy consumed (TBtu)				12.5	30.2	8.5		51.2
Fuel produced (TBtu)								2,088
Energy intensity (Btu/Btu)				0.0060	0.0145	0.0041		0.0245
Oil sands extraction/processing								
Energy consumed (TBtu)		38.7			154.7	3.2		196.6
Fuel produced (TBtu)								431
Energy intensity (Btu/Btu)		0.0897			0.3587	0.0074		0.4559
Total oil extraction/processing								
Energy consumed (TBtu)		38.7		12.5	184.9	11.7		247.8
Fuel produced (TBtu)								2,520
Energy intensity (Btu/Btu)		0.0154		0.0050	0.0734	0.0046		0.0983
Natural gas extraction/processing								
Basis: 1987 Alberta								
Energy consumed (TBtu)					216.9	13.7		230.600
Fuel produced (TBtu)								2,460
Energy intensity (Btu/Btu)					0.0882	0.0056		0.0938
Uranium extraction/refining								
Basis: CEC engineering analysis								
Energy intensity (Btu/Btu)				0.00076	0.017		0.04626	0.0640

c. Electricity production energy requirements

	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Alberta Electricity	Pennsylvania Electricity	Total
Fuel consumed (TBtu)								
Michigan (1989)	676.1	0	15.9	2.7	2			696.7
Alberta (1988)	348.8				18.9			367.8
Pennsylvania (1989)	1057.9	6.8	70.8	11.5	4.1			1151.1
Electricity delivered (TBtu)								
Michigan (1989)								271
Alberta (1988)								123
Pennsylvania (1989)								496
Energy intensity (Btu consumed/Btu delivered)								
Michigan (1989)	2.4927	0.0000	0.0586	0.0100	0.0074			2.5687
Alberta (1988)	2.8331	0.0000	0.0000	0.0000	0.1538			2.9870
Pennsylvania (1989)	2.1308	0.0137	0.1426	0.0232	0.0083			2.3185

d. Flaring energy requirements

California Energy Commission flaring factors	
Basis: 1987 US	
Oil production	0.87 MMcf consumed/TBTU produced (natural gas)
Natural gas production	6.13
Unit conversion	0.001 TBtu/MMcf
Converted energy intensity	
Oil production	
per Btu oil field production	0.00087 Btu consumed/Btu produced (natural gas)
Field/total oil ratio	82.9%
per Btu total oil production	0.0007210 Btu consumed/Btu produced (natural gas)
Natural gas production	0.00613 Btu consumed/Btu produced (natural gas)

e. Transportation energy requirements

Coal transportation

California Energy Commission coal train assumptions	
Basis: 1982 US	
Annual transportation energy requirement	79.90 TBtu/yr (diesel)
Annual coal production	18,640 TBtu/yr
Typical trip distance	700 miles/trip
CEC coal transportation factor	0.00000 Btu consumed/Btu delivered/mile traveled
Ontario coal delivery distance data	
Western Canada Coal	2,250 miles (Red Deer --> Toronto)
Pennsylvania Coal	425 miles (Altoona PA --> Toronto)
Coal energy intensity	
Western Canada Coal	0.0138 Btu consumed/Btu delivered (diesel)
Pennsylvania Coal	0.0026 Btu consumed/Btu delivered (diesel)

Oil transportation

California Energy Commission oil pipeline assumptions	
Basis: pipeline engineering calculations	
Engine oil/gas requirement	0.01 Btu consumed/Btu transported (oil and gas)
Engine efficiency	10,000 Btu input/hp-hr output 25.4% Btu output/Btu input
Pipeline distance	800 miles
CEC oil pipeline factor	0.00000 Btu engine output/Btu transported/mile
Western Canada oil data	
Electric motor efficiency	92.0% Btu output/Btu input
Pipeline distance	2,250 miles (Red Deer --> Toronto)
Crude oil transportation energy intensity	0.0071 Btu output/Btu transported 0.0078 Btu input/Btu transported (electricity)

Natural gas transportation

Basis: 1991 TransCanada PipeLines

Monthly fuel ratios for Eastern Toll Zone

January	7.13%	Btu unaccounted for/Btu delivered
February	9.25%	
March	7.56%	
April	8.19%	
May	6.20%	
June	7.45%	
July	9.14%	
August	7.27%	
September	6.86%	
October	6.86%	
November	7.36%	
December	7.53%	
Average of 12 months	7.57%	Btu unaccounted for/Btu delivered
Methane fugitive emissions (see below)	0.03%	Btu leaked/Btu transported
Transportation combustion factor	7.54%	Btu consumed/Btu delivered

2.End use emission coefficients: fossil fuels

	Coal	Coke	Heavy Oils	Light Oils	Natural Gas	Emission Factor Source
Carbon dioxide						
Emission coefficient	99.00	94.42	71.54	73.11	49.68	Environment Canada 1990, CO2 Inventory
Factor units	tonne/T.	tonne/T.	tonne/T.	tonne/T.	tonne/TJ	
Unit conversion	2.333	2.333	2.333	2.333	2.333	
Converted coefficient (lb/MMBtu)	231.0	220.3	166.9	170.6	115.9	
Methane						
Emission coefficient	0.03		1	0.052	3	USEPA, AP-42
Factor units	lb/ton		lb/Mgal	lb/Mgal	lb/MMcf	
Unit conversion	25		150	141	1000	
Converted coefficient (lb/MMBtu)	0.0012	0.0012	0.0067	0.0004	0.0030	
Nitrous oxide						
Emission coefficient	0.0686		0.0890	0.0890	0.0178	Environment Canada, 1991 Greenhouse Inventory
Factor units	g/kg		g/kg	g/kg	g/kg	
Unit conversions	0.00100		0.00821	0.00721	0.00005	
g/kg -> lb/lb	0.001		0.001	0.001	0.001	
lb/volume	2,000		8,211	7,208	50,000	
MMBtu/volume	25		150	141	1,000	
Converted coefficient (lb/MMBtu)	0.0055	0.0055	0.0049	0.0045	0.0009	

3.Fugitive coefficients

a. Coal mathane leaks

Environment Canada leak factors	
Surface mines (western Canada)	1.2 kg CH4 released/tonne coal mined
Deep mines (Pennsylvania)	16.45 kg CH4 released/tonne coal mined
Conversion factors	2.21 lb/kg
	0.0125 MMBtu/lb Alberta coal
	0.0135 MMBtu/lb Pennsylvania coal
Converted fugitive coefficients	
Surface mines (western Canada)	0.0960 lb CH4 released/MMBtu mined
Deep mines (Pennsylvania)	1.2185 lb CH4 released/MMBtu mined

b. Natural gas pipeline leaks

Environment Canada leak factors		
Production	0.25%	of production
	0.2506%	of delivery to transmission
Transmission	0.03%	of deliveries to distribution/large end users
Distribution	0.05%	of deliveries to small end users
Fuel cycle total	0.3056%	of delivery to end users

(Consistent with Environment Canada, fuel cycle totals include production, transmission, and 50% of distribution)

Conversion factors	
Methane density	0.045 lb/cf
Heat content	1000 Btu/cf natural gas
Converted fugitive coefficients	
Natural gas fuel cycle	0.1375 lb/MMBtu delivered